# Environmental Projects: Volume 15

## Environmental Assessment:
## Proposed 1-Megawatt Radar Transmitter
## at the Mars Site

Goldstone Deep Space Communications Complex

**JPL**
Jet Propulsion Laboratory
California Institute of Technology

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National Aeronautics and
Space Administration

October 15, 1992

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ABSTRACT


The Goldstone Deep Space Communications Complex (GDSCC), located in the Mojave Desert about 64.5 km (40 mi) north of Barstow, California, and about 258 km (160 mi) northeast of Pasadena, California, is part of the National Aeronautics and Space Administration's (NASA's) Deep Space Network (DSN), one of the world's larger and more sensitive scientific telecommunications and radio navigation networks. The Goldstone Complex is managed, technically directed, and operated for NASA by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology in Pasadena, California.

Activities at the GDSCC support the operation of six parabolic dish antennas located at five separate sites called Deep Space Stations (DSSs). Four sites, named Echo, Mars, Uranus, and Apollo, are operational for space missions, while the remaining Venus Site is devoted to research and development activities.

The Mars Site at the GDSCC contains two antennas: the Uranus antenna (DSS 15, 34 m) and the Mars antenna (DSS 14, 70 m). This present volume deals solely with the DSS-14 Mars antenna.

The Mars antenna not only can act as a sensitive receiver to detect signals from spacecraft, but it also can be used in radar astronomy as a powerful transmitter to send out signals to probe the solar system.

At present, the Mars antenna operates as a continuous-wave microwave system at a frequency of 8.51 GHz at a power level of 0.5 MW. JPL has plans to upgrade the Mars antenna to a power level of 1 MW.

Because of the anticipated increase in the ambient levels of radio-frequency radiation (RFR), JPL retained Battelle Pacific Northwest Laboratories (BPNL), Richland, Washington, to conduct an environmental assessment with respect to this increased RFR.

This present volume is a JPL-expanded version of the BPNL report titled *Environmental Assessment of the Goldstone Solar System Radar*, which was submitted to JPL in November 1991. This BPNL report concluded that the operation of the upgraded Mars antenna at the GDSCC, with its increased potential electromagnetic radiation hazards and interferences, would have no significantly adverse biological, physical, or socioeconomic effects on the environment.

Thus, a Finding of No Significant Impact (FONSI) is appropriate in accordance with local, State, Federal, and NASA environmental rules and regulations.

# ACKNOWLEDGMENTS

GLOSSARY

| | |
|---|---|
| A | ampere(s) |
| ACGIH | American Conference of Governmental Industrial Hygienists |
| AFFTC | U.S. Air Force Flight Test Center |
| AGL | Above Ground Level |
| ANSI | American National Standards Institute |
| ARTCC | Air Route Traffic Control Center, Los Angeles, California |
| BBB | Blood-Brain Barrier |
| BLM | U.S. Bureau of Land Management |
| BPNL | Battelle Pacific Northwest Laboratories, Richland, Washington |
| CCB | Complex Control Board (for R-2508) |
| CDRH | Center for Devices and Radiological Health |
| CEQ | Council on Environmental Quality (Federal) |
| CFR | Code of Federal Regulations |
| $cm^2$ | square centimeter(s) |
| CNS | Central Nervous System |
| CW | Continuous Wave |
| db | decibel(s) |
| deg | degree(s) |
| dia | diameter(s) |
| DSCC | Deep Space Communications Complex |
| DSN | Deep Space Network |
| DSS | Deep Space Station |
| E | Electrical Field |
| EA | Environmental Assessment |
| EEG | Electroencephalogram |
| EIS | Environmental Impact Statement |
| EKG | Electrocardiogram |
| ELF | Extremely Low Frequency |
| EMF | Electromagnetic Field |
| EMR | Electromagnetic Radiation |
| EO | Electro-Optical |
| EPA | U.S. Environmental Protection Agency (also U.S. EPA) |
| FAA | Federal Aviation Administration |
| FCC | Federal Communications Commission |
| FONSI | Finding of No Significant Impact |
| ft | foot (feet) |
| GCF | Ground Communications Facility |
| GDSCC | Goldstone DSCC |
| GHz | gigahertz |
| h | hour(s) |
| H | Magnetic Field |
| HEF | High-Efficiency (Antenna) |
| Hz | hertz |
| IEEE | Institute of Electrical and Electronic Engineers |
| in. | inch(es) |
| J | joule(s) |
| JPL | Jet Propulsion Laboratory, Pasadena, California |
| kg | kilogram(s) |
| kHz | kilohertz |
| km | kilometer(s) |
| m | meter(s) |
| $m^2$ | square meter(s) |
| MBGA | M. B. Gilbert Associates, Long Beach, California |
| mg | milligram(s) |
| MHz | megahertz |

# GLOSSARY (Cont'd)

| | |
|---|---|
| mi | mile(s) |
| MIL-STD | Military Standard |
| min | minute(s) |
| MOA | Military Operating Area |
| MPE | Maximum Permissible Exposure |
| MTF | Microwave Test Facility |
| mW | milliwatt(s) |
| MW | megawatt(s) |
| NASA | National Aeronautics and Space Administration |
| NAVWPNCEN | Naval Weapons Center (also NWC) [as of January 1992, name was changed to Naval Air Weapons Station (NAWS)] |
| NEC-REF | Numerical Electromagnetic Reflector Antenna Code, Ohio State University |
| NEPA | National Environmental Policy Act |
| NIEMR | Non-Ionizing Electromagnetic Radiation |
| NIOSH | National Institute for Occupational Safety and Health |
| NMI | NASA Management Instruction |
| NOAA | National Oceanic and Atmospheric Administration |
| NOCC | Network Operations Control Center |
| NTC | National Training Center (U.S. Army) |
| NTIA | National Telecommunications and Information Administration (formerly OTP) |
| NWC | see NAVWPNCEN |
| OTP | Office of Telecommunications Policy (see NTIA) |
| ppm | parts per million |
| R&D | Research and Development |
| RADAR | Radio Detection and Ranging |
| RAPCON | Radar Approach Control, Edwards Air Force Base |
| RF | Radio Frequency |
| RFEM | Radio-Frequency Electromagnetic |
| RFR | Radio-Frequency Radiation |
| RS | Research System |
| s | second(s) |
| SAR | Specific Absorption Rate |
| SETI | Search for Extraterrestrial Intelligence |
| SMR | Specific Metabolic Rate |
| STS | Space Transportation System (Space Shuttle) |
| TDA | Office of Telecommunications and Data Acquisition (JPL) |
| TDS | Total Dissolved Solids |
| TFW | Tactical Flight Wing (35th), Edwards Air Force Base |
| UHF | Ultra High Frequency |
| USAF | U.S. Air Force |
| U.S. EPA | see EPA |
| USSR | Union of Soviet Socialist Republics |
| UST | Underground Storage Tank |
| V | volt(s) |
| VHF | Very High Frequency |
| VLBI | Very Long Baseline Interferometry |
| W | watt(s) |

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SECTION I

INTRODUCTION


A.    BACKGROUND

      The Goldstone Deep Space Communications Complex (GDSCC), located in the
Mojave Desert about 64.5 km (40 mi) north of Barstow, California, and about
258 km (160 mi) northeast of Pasadena, California, is part of the National
Aeronautics and Space Administration's (NASA's) Deep Space Network (DSN), one of
the world's larger and more sensitive scientific telecommunications and radio
navigation networks.  The Goldstone Complex is managed, technically directed,
and operated for NASA by the Jet Propulsion Laboratory (JPL) of the California
Institute of Technology in Pasadena, California.  A detailed description of the
GDSCC is presented in Section V of this publication.

      The GDSCC includes five distinct operational areas named Echo Site, Venus
Site, Mars Site, Apollo Site, and Mojave Base Site.  Within each of the first
four sites is a Deep Space Station (DSS) that consists of at least one parabolic
dish antenna and support facilities.  Although there are four DSN operational
sites at the GDSCC, there now are six operational parabolic dish antennas
because two antennas are located at the Mars Site and two are at the Apollo
Site.  The Mojave Base Site, while it is part of the GDSCC, is not part of the
DSN but is operated by the National Oceanic and Atmospheric Administration
(NOAA).


B.    THE SCIENCE OF RADAR ASTRONOMY

      Throughout history, the science of astronomy has been a passive human
endeavor.  Astronomers, located at ground-based observatories and telescopes,
had to passively await the arrival of various electromagnetic signals that had
been either emitted or reflected from diverse celestial objects.  Astronomers
could only observe, not manipulate, the heavens.

      This state of astronomical investigation changed somewhat following World
War II when an invention called radar (radio detection and ranging) had been
perfected for military purposes.  Radar permitted astronomical observations of
the solar system to become an active human endeavor.

      Radar astronomers now could manipulate the heavens.  No longer dependent
upon electromagnetic signals pouring in from outer space, they now could use a
radar transmitter to generate their own strong electromagnetic signals.  Radar
astronomy particularly is applicable to probe the solar system because the
distances between solar system objects are relatively small as compared to the
great distances between objects in the rest of the universe.

The transmitted electromagnetic signals, generated by radar, travel into space until they encounter and strike an object within the solar system. Reflected back from the object, the now greatly weakened radar echoes return to Earth where they are detected by extremely sensitive receivers. Analysis of the reflected radar signals represents a powerful tool to provide information about the nature of the solar system object that the radar-generated electromagnetic signals had encountered.

Thus, since the early 1960s, Earth-based radars have revealed increasingly refined information about the solar system: planetary orbits, and surface structures and compositions and geology of the planets and their moons, ranging from nearby Mercury and Venus to as far away as Saturn. Details about planetary physics, often not obtainable except by radar astronomy, are critically important in the design and planning of spacecraft flight missions to the planets.

C.     RADAR ASTRONOMY AT THE GOLDSTONE DEEP SPACE COMMUNICATIONS COMPLEX (GDSCC)

Activities at the GDSCC support the operation of six parabolic dish antennas located at five separate DSSs. The four DSSs that are operational for space missions are named Echo Site, Apollo Site, Uranus Site, and Mars Site. The remaining fifth DSS, called Venus Site, is devoted to research and development (R&D) activities.

The Mars Site at the GDSCC contains two antennas: the Uranus antenna (DSS 15, 34 m), and the Mars antenna (DSS 14, 70 m). The Mars antenna not only can act as a sensitive receiver to detect signals from spacecraft, but it also can be used in radar astronomy as a powerful transmitter to send out strong electromagnetic signals to probe the solar system, and as a highly responsive receiver to detect reflected radar echoes.

At present, the Mars antenna operates as a continuous wave (CW) microwave system at a frequency of 8.51 GHz at a power level of 0.5 MW. Today, the transmission power of the Mars antenna can be increased by taking advantage of the steady increase in available transmitter power that has taken place in the last 26 years since the Mars antenna first was constructed. With an increase in transmitted power, then for a given target, the strength of the reflected signal received back at Earth also would increase.

Combined with recent improvements in receiver technology that reduce the level of noise in the receiver, the two positive effects of a stronger received signal and reduced noise level will produce a more desirable signal-to-noise ratio.

Thus, if the transmitted power of the Mars antenna would be increased to 1 MW, the radar beam could reach out farther into the solar system and be able to investigate objects that now are too far away to yield a reflected radar echo strong enough to be detected at the receiver. The more extended beam of the 1-MW transmitter of the Mars antenna would provide new solar system targets that would become available to the radar astronomer.

D.    UPGRADE OF THE POWER LEVEL OF THE MARS ANTENNA AT THE GDSCC

Because of the above-mentioned advantages of having greater transmission power for the Mars antenna, JPL has decided to double the power level of the DSS-14 transmitter from its present-day 0.5 MW to 1 MW.

But, such increase in power transmission will result in an increase in the levels of radio-frequency radiation (RFR) in the area around the Mars antenna. This increased electromagnetic radiation (EMR) potentially could lead to environmental radiation hazards and to potential electromagnetic interferences.

This present volume, therefore, is a report on the environmental assessment (EA) of any possible environmental hazards engendered by the doubling of the power level of the Mars antenna's transmitter power from 0.5 MW to 1 MW.

E.    THE NO-ACTION ALTERNATIVE

Using well-established safety procedures, the DSS-14 antenna now operates safely at the Mars Site at the GDSCC at an RFR-power level of 0.5 MW. If no action was taken, then any possible environmental problems that could arise from upgrading the radar transmitter to a greater RFR-power level of 1 MW would not be addressed. Thus, the no-action alternative, although considered, is not a viable substitute for the consideration of the potential environmental hazards that possibly could arise from upgrading of the power level of the DSS-14 transmitter, as discussed in this EA.

F.    CONCLUSION

This EA reports a Finding of No Significant Impact (FONSI) on the GDSCC environment, in accordance with local, state, Federal and NASA environmental rules and regulations, and in accordance with safety standards published by various technical agencies.

SECTION II

ENVIRONMENTAL ASSESSMENT OF THE NEW 1-MW TRANSMITTER
AT THE MARS SITE (DSS 14) AT THE GDSCC


A.    REQUIREMENT OF AN ENVIRONMENTAL ASSESSMENT (EA)

     The proposed doubling of the power level of the transmitter of the DSS-14
antenna at the Mars Site at the GDSCC requires an EA document that records the
existing environmental conditions at the Mars Site, analyzes the environmental
effects that possibly could be expected from the doubling of the power level of
the DSS-14 transmitter, and recommends measures that could be taken to mitigate
any possibly deleterious environmental effects.

     The need for an EA document had its origin in 1978, when the Federal
Council on Environmental Quality (CEQ) issued regulations under the Code of
Federal Regulations (CFR) (40 CFR Parts 1500-1508) to implement the procedural
requirements of the National Environmental Policy Act (NEPA).  Following this
action, the NASA procedures to implement NEPA were published in 14 CFR Subparts
1216.1 and 1216.3.  The NASA procedures have been incorporated in the NASA
Directives System as NASA Management Instruction (NMI) 8800.7.

     Thus, NASA installations planning qualifying projects must prepare an EA
document (14 CFR 1216.304).  As defined in 40 CFR Subpart 1508.9, Preparation of
Environmental Assessments, the purpose of the EA is to provide sufficient
evidence and analysis to permit the determination whether to prepare an
Environmental Impact Statement (EIS) or a Finding of No Significant Impact
(FONSI).

     The EA report must be completed and a decision made as to whether an EIS
is required prior to beginning detailed project definition and planning [NASA,
1980].  Evaluation of environmental impacts, therefore, must commence at the
onset of project conception.  In addition to assessing the probable impacts
resulting from the proposed project, the EA must provide an evaluation of
alternatives to the proposed project, including the alternative of "no action."
While there is no requirement to select the alternative that has the least
environmental impact, the rationale for selecting the favored alternative must
be provided.


B.    SCOPE OF THE EA

     Doubling of the power level of the DSS-14 transmitter from 0.5 to 1 MW
obviously will result in an increase of radio-frequency radiation (RFR) in the
vicinity of the antenna.  This expected increase in the ambient levels of RFR,
and its environmental consequences, if any, is the only issue addressed by this
EA.

     Because the DSS-14 transmitter, operating at a power level of 0.5 MW, is
an already established facility at the Mars Site, the upgrade of the transmitter
to a power level of 1 MW requires no significant construction to be carried out
at the Mars Site.  Thus, it was not necessary in this EA to consider any
environmental consequences that could arise from the construction of any new
facilities at the Mars Site.

## C.    CALCULATIONS USED IN THE EA

At present, the DSS-14 Mars transmitter operates as a CW microwave system at a frequency of 8.51 GHz at a power level of 0.5 MW.  When the transmitter is upgraded, its power level will rise to 1 MW.

Detailed theoretical calculations were carried out to estimate both the magnitude and distribution of the RFR to be expected from the upgraded system. The resulting values then were used to estimate the effects, if any, upon humans, animals, and the environment.  Details of these studies, along with a description of the methods employed, are shown in Appendixes A and B.


## D.    ENVIRONMENTAL CONSIDERATIONS OF THE INCREASED RFR FIELD AT GROUND LEVEL OF THE MARS SITE

Results of the calculations of the increased RFR field to be expected in the vicinity of the upgraded DSS-14 transmitter at the Mars Site indicate that humans located at a perimeter of and beyond 610 m (2,000 ft) will never be exposed to levels of average power density greater than those allowed by the draft 1991 American National Standards Institute/Institute of Electrical and Electronics Engineers Standard [ANSI/IEEE-STD-SCC28, 1991].

This conclusion is based upon the DSS-14 transmitter operating at its maximum-rated power level, but at an elevation of 10 deg or greater.

The draft 1991 ANSI/IEEE Standard allows a maximum permissible exposure (MPE) to RFR, at a frequency of 8.51 GHz in an "uncontrolled environment," to be about 5.7 mW/cm$^2$ averaged over any 10.6-min period.

This MPE to RFR is far greater than the 1 mW/cm$^2$ average maximum power density to be expected at distances of 610 m (2,000 ft) from the antenna.  In addition, at even greater distances, the average maximum power density would fall precipitously and attain levels too low to be measured using broadband microwave hazard instrumentation that is now available.

But, what if the antenna was operated at elevations less than 10 deg?  If the antenna operated at a zero-degree elevation, then the average power density level could exceed both the "controlled" and "uncontrolled" ANSI/IEEE criteria at ground-level points that were directly under the main beam of the antenna.

> WARNING:  The conclusions of this EA, therefore, are based upon the assumption that the DSS-14 antenna's 1-MW radar transmitter will _never_ be operated at elevations below 10 deg.


## E.    ENVIRONMENTAL CONSIDERATIONS OF THE INCREASED RFR FIELD IN THE AIRSPACE ABOVE THE MARS SITE

The GDSCC is located within the R-2508 complex airspace, which is "owned" and managed by four major military groups:  Air Force Flight Test Center (AFFTC); Edwards Air Force Base, 35th Tactical Fighter Wing (TFW); George Air Force Base, National Training Center (NTC); and Fort Irwin and Naval Weapons Center (NAVWPNCEN), China Lake, California.  The complex consists of several Military Operating Areas (MOAs) and a civilian air corridor (Daggett shelf).

Air traffic control responsibilities for the R-2508 complex, from 0600-2200 local time Monday-Friday and 0600-2000 Saturdays and Sundays, are delegated to Edwards Radar Approach Control (RAPCON), a Federal Aviation Administration (FAA) air traffic control system. When Edwards RAPCON is closed, air control authority is delegated to the Air Route Traffic Control Center (ARTCC), Los Angeles, California. Figure 1 illustrates the R-2508 complex in relation to local landmarks [Complex Control Board, 1991].

Most air traffic in this area normally is of a transition type (aircraft climbing and descending from one altitude to another). This makes it difficult to predict altitudes in use during any given period.

Are there hazards to humans in aircraft that fly through the DSS-14 radar transmitter's beam? People in aircraft flying through the 1-MW beam of the upgraded DSS-14 transmitter could be exposed to average power densities of 100 mW/cm$^2$ or greater. Obviously, this value exceeds the draft 1991 ANSI/IEEE Standard for RFR exposure.

The time-averaging provisions of the draft 1991 ANSI/IEEE Standard, however, allow RFR exposures of 100 mW/cm$^2$ for about 36 s. This certainly is a longer time than any aircraft would take to traverse through the antenna's beam. Thus, such aircraft RFR exposures would fall below the draft 1991 ANSI/IEEE Standard.

But, present-day NASA/JPL airspace coordination policies for the GDSCC do not permit such aircraft exposures to occur at all. The EA assumed, therefore, that airspace coordination, similar to that already being followed and success-fully employed for all other RFR emitters at the GDSCC, also will be enforced for the operation of the 1-MW radar transmitter at the DSS-14 antenna at the Mars Site.

F.    SAFETY PLAN

The calculated values obtained in this EA are conservative because the analyses used "worst-case" parameters. But, in addition to these derived theoretical values, it will be necessary to use appropriate broadband microwave instrumentation to measure and quantify the actual RFR levels in the vicinity of the antenna when the upgraded facility becomes operational.

Battelle Pacific Northwest Laboratories (BPNL) will provide guidance to JPL on the development of a safety plan that will detail necessary procedures to quantify RFR levels to within 610 m (2,000 ft) of the upgraded antenna. This safety plan will be approved by JPL before the 1-MW transmitter becomes operational.

> WARNING: It is important that GDSCC personnel should not approach within 100 m (330 ft) of the operating 1-MW antenna until a survey of the radio-frequency (RF) field indicates that the measured power density is below the established acceptable limits.
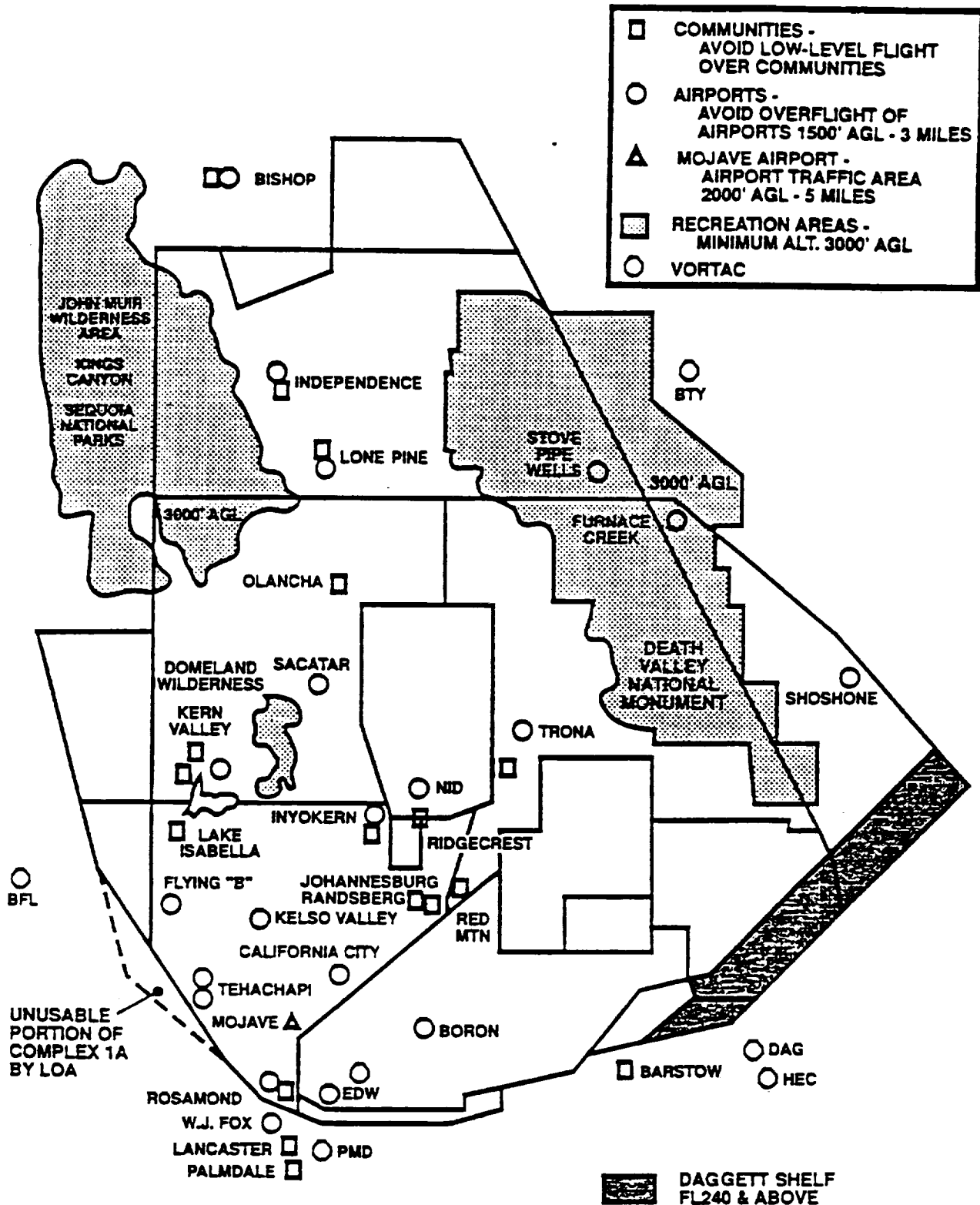
Figure 1.  The R-2508 Airspace Complex

SECTION III

THE DEFINITION, MEASUREMENT, AND PROLIFERATION OF AND EXPOSURE TO
RADIO-FREQUENCY RADIATION

The doubling of the power level of the DSS-14 transmitter at the Mars Site
at the GDSCC will be accompanied by an increase in radio-frequency radiation
(RFR) at the Mars Site vicinity.  To properly assess the possible biological and
physical environmental effects of this increase in RFR, this section defines
RFR, the units used to measure it, and the standards that have been developed to
ensure safe exposures to the RFR.

A.    DEFINITION OF RFR AS USED IN THIS EA

In consideration of the effects of exposure to RFR on the health of
humans, plants, and animals, the term "RFR" is used as a generic term that
includes other radiations commonly found in the bioeffects literature:
electromagnetic radiation (EMR), non-ionizing electromagnetic radiation (NIEMR),
microwave radiation, radio-frequency electromagnetic (RFEM) fields,
electromagnetic fields (EMFs), microwave fields, and others.  The frequency
range of primary interest to the 1982 ANSI Standard [ANSI-STD-C95.1] runs from
3 kHz to 300 GHz.  The operating frequency of the DSS-14 transmitter is 8.51 GHz
and falls within the 1982 ANSI Standard range.

B.    UNITS TO MEASURE RFR POWER LEVELS

Obviously, any quantitative discussion of the possible physical and
physiological effects of RFR requires the use of a consistent set of measurement
units.  Following common usage, the values of radiation intensity are expressed
as power density units of milliwatts per square centimeter ($mW/cm^2$).  Consistent
with the national policy of using metric units, the unit for area is square
centimeters ($cm^2$).  Because land surveying, however, is still based on English
units of length, distances and dimensions ordinarily are expressed in feet (ft).
The accepted unit for electric field intensity is volts per meter (V/m).

C.    WIDESPREAD SOCIAL PROLIFERATION OF RFR-EMITTING DEVICES AND SYSTEMS

Public use of electronic devices that generate RFR and the acceptance of
their benefits have been growing almost exponentially over a number of years.
Public television and radio broadcasting stations, ham-radio transmitters,
citizen-band radios, ground-level and satellite communication systems, civil and
military aircraft navigation systems, airport traffic control systems, medical
diathermy units, defense tracking systems, remote garage-door opening devices,
microwave ovens, cellular phone systems, and a variety of units for industrial
heating and processing contribute to the increase of RFR emitted in this
country.

All of these devices are regulated by the Federal Government, mainly the
Federal Communications Commission (FCC), and all are restricted to specific
frequency bands.  Civilian use of the radio spectrum is under the control of the
FCC while government use is under the control of the National Telecommunications
and Information Administration (NTIA), formerly the Office of Telecommunications
Policy (OTP).

The power levels that most devices may emit are also restricted. Yet, as the number of these devices has increased, the background level of RFR in this country, particularly in urban and industrial centers, has increased as well. It is appropriate, therefore, to ask whether these increasing levels of RFR will be deleterious to human health.

Various agencies of the Federal Government have established programs to deal with the question of effects of RFR on human health. In the interest of personnel safety, the U.S. Air Force has taken an active role for more than 20 years to advance the state of knowledge of RFR bioeffects. The Environmental Protection Agency (EPA) has conducted a study of environmental levels of RFR. The Center for Devices and Radiological Health (CDRH) has promulgated a performance standard for permissible microwave oven leakage. The National Institute for Occupational Safety and Health (NIOSH) is investigating the use of industrial microwave devices. The U.S. Air Force, together with the Army, Navy, and other governmental agencies, maintains research programs on the biological effects of RFR, with the objective of assessing effects on human health. The results of these programs indicate that the biological effects of RFR are largely confined to average power densities exceeding about 1 $mW/cm^2$.

In summary, the benefits of the ever-increasing number of RFR-generating devices for communications, radar, personal and home use, and industrial processes are widely accepted. On the other hand, many people are concerned that the proliferation of the use of RFR devices, including various military radar and communications systems, may be associated with some as-yet-undefined hazardous biological effects. The purpose of this publication is to address such concerns as they pertain to the upgrading of the power level of the DSS-14 transmitter at the Mars Site at the GDSCC from 0.5 MW to 1 MW.

D.    STANDARDS PROMULGATED TO ENSURE SAFETY IN EXPOSURE TO RFR

A rational discussion of any possible health effects resulting from exposure to RFR must involve consideration of what are known as exposure standards or RFR Protection Guides.

Exposure standards generally are applied to specifications or guidelines for permissible occupational and/or non-occupational exposure of humans to electromagnetic fields. The standards are expressed as maximum power densities or field intensities in specific frequency ranges and for indicated exposure durations.

In 1991, the ANSI/IEEE Subcommittee SCC28 developed a draft frequency-dependent standard [ANSI/IEEE-STD-SCC28] for both occupational and general-public exposure to RFR, to replace the ANSI RFR Protection Guides, published in 1982. The 1982 ANSI RFR Protection Guides, shown in Table 1, were derived from analyses of many representative experimental and theoretical results selected by a subcommittee of ANSI. The 1982 ANSI RFR Protection Guides have been widely adopted throughout the United States, and undoubtedly the 1991 version also will be accepted.

The 1982 ANSI RFR Protection Guides cover the frequency range from 300 kHz to 100 GHz and are based on a mean whole-body specific-absorption rate (SAR) limit of 0.4 W/kg instead of a constant incident power density. SAR is defined as the rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body. The lowest limit, 1 $mW/cm^2$, is for the range from 30 to 300 MHz. It is within this frequency that the human body acts as a resonant antenna, and its RFR absorption is greatest.

Table 1.  1982 ANSI Radio-Frequency Radiation Protection Guides

| Frequency Range (MHz) | $E^2$ ($V^2/m^2$) | $H^2$ ($A^2/m^2$) | Power Density ($mW/cm^2$) |
|---|---|---|---|
| 0.3 — 3.0 | 400,000 | 2.5 | 100 |
| 3.0 — 30 | 4,000 ($900/f^2$) | 0.25 ($900/f^2$) | $900/f^2$ |
| 30 — 300 | 4,000 | 0.025 | 1.0 |
| 300 — 1,500 | 4,000 ($f/300$) | 0.025 ($f/300$) | $f/300$ |
| 1,500 — 100,000 | 20,000 | 0.125 | 5.0 |

Note:  f is the frequency in MHz.

The value 0.4 W/kg includes a safety factor of 10, and the specified limits are not to be exceeded for exposures averaged over any 0.1 h period.

In the far field of an RFR source, the governing maximum values of exposure are the power densities shown in Table 1 along with the corresponding squares of the electric- and magnetic-field amplitudes ($E^2$ and $H^2$).  The latter values are approximate "free-space" equivalents.  In the near field of an RFR source, the governing maxima are the values of $E^2$ and $H^2$, but can be expressed in terms of corresponding equivalent power densities.

According to the 1982 ANSI RFR Protection Guides, the power density limits for the DSS-14 transmitter operating at 8.51 GHz is 5 mW/cm$^2$.  This will be increased to 10 mW/cm$^2$ in the draft 1991 ANSI/IEEE RFR Protection Guides for exposures in so-called "controlled environments."  In "uncontrolled environments," the draft 1991 ANSI/IEEE RFR Protection Guides limit is reduced to 5.7 mW/cm$^2$.

The 1990 American Conference of Governmental Industrial Hygienists (ACGIH) Standard is also based on an SAR of 0.4 W/kg.  But this value is for occupational exposures only.  The major difference of the ACGIH Standard, as compared to the 1982 ANSI RFR Protection Guides, is that the 1 mW/cm$^2$ value extends only from 30 to 100 MHz and then rises from the latter value with a slope of f/100 to 10 mW/cm$^2$ at 1 GHz.  This difference is based on the premise that children, who have a higher whole-body resonant frequency than do adults, are not likely to be occupationally exposed to RFR.  Another difference is that the lower frequency limit for the 1990 ACHIH Standard is at 10 kHz instead of 300 kHz.

The draft 1991 ANSI/IEEE RFR Protection Guides for controlled and uncontrolled environments are shown in Tables 2 and 3, respectively.  The draft 1991 ANSI/IEEE RFR Protection Guides also limit SAR to less than 0.4 W/kg in "controlled environments," and to 1/5 of that in "uncontrolled environments."  A controlled environment is defined by the draft 1991 ANSI/IEEE RFR Protection Guides as location(s) where there is exposure that may be incurred by workers who knowingly accept potential exposure as a condition of employment, or exposure of individuals who knowingly accept potential exposure for whatever reason other than a condition of employment, or incidental exposure during transient passage through areas where analysis shows that the exposure levels

may be above those shown in Table 3 but do not exceed those in Table 2. An uncontrolled environment is defined as location(s) where there is exposure of individuals to RFR who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 3. The averaging time is the time period over which exposure is averaged to determine compliance with the MPE stated in the draft 1991 ANSI/IEEE RFR Protection Guides.

Table 2. Draft 1991 ANSI/IEEE Radio-Frequency Radiation Protection Guides: Maximum Permissible Exposure (MPE) for Controlled Environments

| Frequency Range (MHz) | E (V/m) | H (A/m) | Power Density (mW/cm$^2$) | Averaging Time $\lvert E \rvert^2$ or W (min) | Averaging Time $\lvert H \rvert^2$ (min) |
|---|---|---|---|---|---|
| 0.003 − 0.1 | 614 | 163 | (100, 1,000,000)* | 6 | 6 |
| 0.1 − 3.0 | 614 | 16.3/f | (100, 10,000/f$^2$)* | 6 | 6 |
| 3.0 − 30 | 1842/f | 16.3/f | (900/f$^2$, 10,000/f$^2$)* | 6 | 6 |
| 30 − 100 | 61.4 | 16.3/f | (1.0, 10,000/f$^2$)* | 6 | 6 |
| 100 − 300 | 61.4 | 0.163 | 1.0 | 6 | 0.0636f$^{1/3}$ |
| 300 − 3,000 | − | − | f/300 | 6 | 30 |
| 3,000 − 15,000 | − | − | 10 | 6 | − |
| 15,000 − 300,000 | − | − | 10 | 616,000/f$^{1/2}$ | − |

*These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequency and are displayed on some instruments in use. The first number applies to the E field and the second number applies to the H field.

Note: f is the frequency in MHz.

Table 3. Draft 1991 ANSI/IEEE Radio-Frequency Radiation Protection Guides:
Maximum Permissible Exposure (MPE) for Uncontrolled Environments

| Frequency Range (MHz) | E (V/m) | H (A/m) | Power Density $(mW/cm^2)$ | Averaging Time $|E|^2$ or W (min) | Averaging Time $|H|^2$ (min) |
|---|---|---|---|---|---|
| 0.003 − 0.1 | 614 | 163 | $(100, 1,000,000)$* | 6 | 6 |
| 0.1 − 1.34 | 614 | $16.3/f$ | $(100, 10,000/f^2)$* | 6 | 6 |
| 1.34 − 3.0 | $823.8/f$ | $16.3/f$ | $(180/f^2, 10,000/f^2)$* | $f^2/0.3$ | 6 |
| 3.0 − 30 | $823.8/f$ | $16.3/f$ | $(180/f^2, 10,000/f^2)$* | 30 | 6 |
| 30 − 100 | 27.5 | $158.3/f^{1.668}$ | $(0.2, 940,000/f^{3.336})$* | 30 | $0.0636f^{1/3}$ |
| 100 − 300 | 27.5 | 0.0729 | 0.2 | 30 | 30 |
| 300 − 3,000 | − | − | $f/1500$ | 30 | − |
| 3,000 − 15,000 | − | − | $f/1500$ | $90,000/f$ | − |
| 15,000 − 300,000 | − | − | 10 | $616,000/f^{1/2}$ | − |

*These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequency and are displayed on some instruments in use. The first number applies to the E field and the second number applies to the H field.

Note: f is the frequency in MHz.

POSSIBLE ENVIRONMENTAL EFFECTS FROM OPERATION OF THE
1-MW DSS-14 TRANSMITTER AT THE MARS SITE AT THE GDSCC


A.    INTRODUCTION

An important parameter to consider in the assessment of possible
biological and physical environmental effects due to an increase in RFR is the
power density of the radiation emitted in the vicinity of the DSS-14 antenna at
the Mars Site when the transmitter is upgraded to a power level of 1 MW and
operates at a frequency of 8.51 GHz.  Because the antenna operates in a
continuous wave (CW) mode, it will produce RFR energy continuously in short
pulses of seconds or minutes duration.

Because the main radar beam is quite narrow, and will be pointed upwards
at elevations of 10 deg or greater, its RFR will not strike the ground.  Most of
the RFR at ground level, therefore, results from scattered RFR.  In all cases,
the highest values of average power density to which the general public will be
exposed will be just outside the Mars Site boundary, but these values will still
be below the maximum permissible values recommended for "uncontrolled
environments" by the draft 1991 ANSI/IEEE RFR Protection Guides (see Table 3 in
Section III).

Assessing risk to human health and setting standards to protect health, in
general, create extremely complex problems.  In addition to purely technical and
scientific questions, there are problems, still only vaguely recognized,
involving philosophy, law, administration, and feasibility of programs.
Although dealing with these subjects in detail is beyond the scope of this
publication, it is important that they be mentioned.

One distinction between RFR and ionizing radiation is the considerable
experimental evidence for the existence of exposure thresholds for various RFR
effects.  In the review of RFR bioeffects provided by this EA, threshold levels
are considered on a case-by-case basis, with attention being paid to the
physiological mechanisms responsible for a particular effect.


B.    POSSIBLE BIOLOGICAL ENVIRONMENTAL EFFECTS

The basic issue addressed by this EA is whether brief, prolonged, or
continual exposure to the power densities of RFR produced by the upgraded, 1-MW
radar beam of the DSS-14 transmitter is likely to adversely affect the health of
humans.

The primary reference in this EA that deals with this important question
is the U.S. Air Force (USAF) School of Aerospace Medicine report [Heynick,
1987].

Although this USAF report is a critical review of the present state of
knowledge with respect to biological effects of RFR, it does not contain any
system-specific information.  Thus, additional searches of the pertinent
literature were conducted through early 1991.

The most pertinent and scientifically significant research results in the
review and relevant literature were used in the EA to derive the conclusions

regarding possible biological effects upon humans from the RFR to be emitted by the 1-MW radar transmitter. Full details of these specific research results are presented in Appendix C.

Review of the relevant literature indicates there is no reliable scientific evidence to suggest that chronic exposure to the RFR from the 1-MW DSS-14 transmitter would be harmful to the health of humans, even to that of the most susceptible individuals: the unborn, the infirm, or the aged.

There are two ways that humans can be exposed to the RFR emitted by the 1-MW DSS-14 transmitter: on the ground and in the air.

1.  Exposure of Humans on the Ground

Humans on the ground can be exposed to low-intensity RFR at distances of several miles away from the exclusion area immediately around the DSS-14 antenna. The levels of RFR outside the immediate Mars Site boundaries, however, will be so low as to not be detectable by current broadband microwave survey instruments. In no case will equivalent plane-wave power densities exceed 2 $mW/cm^2$ at any point outside of the Mars Site.

Possible exposure of individuals within the Mars Site was not even considered because JPL will provide appropriate protective and control measures. As indicated in Section II.F, a safety plan will be developed, with guidance to JPL from Battelle Pacific Northwest Laboratories (BPNL), to produce procedures required to quantify RFR levels within 610 m (2,000 ft) of the antenna.

Because the GDSCC is in a remote and restricted area, it is highly unlikely that non-GDSCC employees, or the general public, would ever be close to the operating antenna where the calculated RFR levels would be highest.

In any case, the calculated levels of RFR at ground level would be well below the draft 1991 ANSI/IEEE RFR Protection Guides for "uncontrolled areas."

Plants and animals at ground and near-ground levels will be exposed to power densities much lower than those of the 1-MW DSS-14 transmitter's main beam. Table 3 in Section III presents the approximate areas and locations of land near the 1-MW DSS-14 antenna that are calculated to receive various power densities at ground level.

Power-density levels that are incapable of producing substantial heating are not likely to have adverse effects on living organisms. No ground regions will receive RFR power-density levels greater than 2 $mW/cm^2$.

Cataracts involve clouding of the lens of the eye, and their development leads to degraded vision. With respect to possible RFR-induced cataracts, the cataractogenesis threshold found in laboratory animals is about 150 $mW/cm^2$ from protracted exposures. Thus, it is most unlikely that short duration exposure to RFR from the 1-MW DSS-14 transmitter will cause cataracts (or any other ocular abnormalities) in any animals should they enter this area.

In summary, biological effects from exposure to RFR from the 1-MW DSS-14 transmitter at ground or near-ground level, outside the exclusion fence, are not anticipated because of the low power-density levels in that region.

2. Exposure of Humans in Aircraft

Humans flying in aircraft exposed to the main beam of the DSS-14 transmitter is a possibility that is shared with many other operational high-power radar systems. There are few, if any, documented incidents related to harm resulting from humans being exposed to RFR in such situations. There is no reason to believe that the behavior of an operating 1-MW radar beam at the Mars Site would be significantly different from that of other radar installations in this respect.

NASA/JPL policies must ensure that the radar's main beam never intercepts any airborne system out to an altitude of 300 km ($10^6$ ft). This is a conservative distance because there are uncertainties concerning the susceptibility even to low levels of RFR of the new "fly-by-wire" avionics. At the 300-km distance, RFR levels will fall well below 200 V/m. The latter value corresponds to the present-day military specifications for protection against electromagnetic interference effects. So, exposure to the main beam must be avoided.

Due to the proximity of a civilian air corridor (Daggett shelf), and the numerous military flights that occur within Area R-2508 (see Figure 1 in Section II), controls would be placed on the operation of the DSS-14 antenna to prevent the beam from intercepting aircraft. Procedures will be established with neighboring military installations and with the FAA to prevent exposure of aircraft to electric fields greater than 200 V/m (10 mW/cm$^2$ equivalent power density). This limit is based on Military Standards (MIL-STDs) 461 [1987a], 462 [1987b], and 463 [1988]. Calculated models of power density (Figure A.3 in Appendix A) for the DSS-14 transmitter indicate that a conservatively safe level of exposure (0.1 mW/cm$^2$) in the main beam is reached at a distance of 304 km (189 mi, $10^6$ ft).

The safety procedures will include restrictions on the permissible angles of radiation to avoid air corridors, will establish a pre-arranged schedule for transmissions, and will provide airspace avoidance contour plots for cognizant external agencies.

3. Exposure of Airborne Fauna

Biota that could possibly be affected by the main radar beam is airborne fauna: birds and possibly bats, and high-flying insects. The maximum power densities (>100 mW/cm$^2$) that would be encountered, however, are similar to the power densities emitted by other transmitters already at the GDSCC.

For local airborne biota, minor localized effects may occur in the near-field volume around the site. The RFR from the 1-MW DSS-14 transmitter might tend to cause birds to avoid the radar, thereby helping to eliminate the possibility of birds striking it. On the other hand, birds might learn to seek out the RFR for warmth during cold weather. On the basis of existing information, the anticipated effects, if any, on birds are unclear. Moreover, RFR-induced biological effects may vary among bird species because the specific absorption rates (SARs) may be species-dependent. Any potential thermal effects from the 1-MW DSS-14 transmitter would not only be of very short duration but would be very localized as well.

Nonthermal effects on birds from low-level RFR have been claimed by a few researchers, but the methodology used in these experiments has been questioned. Temperatures of the experimental subjects were not measured and the effects may have been thermal. Irrespective of whether the effects were thermal or

nonthermal, the experimental arrangements (caged birds in highly restricted areas with horn antennas mounted on the cages) bear little relationship to the normal habitats of birds. Researchers have concluded that external environmental parameters such as temperature, humidity, and atmospheric pressure, as well as internal factors of the experimental subject, should be considered when analyzing RFR effects on organisms.

The RFR fields emitted by the 1-MW DSS-14 transmitter will be similar to those emitted by existing GDSCC transmitter systems that have been operating continuously for many years without any evident ecological damage. Furthermore, for more than a decade, animal behaviorists and ornithologists have considered radar as a legitimate tool for studying animal migration, navigation, and homing [Eastwood, 1967; Krupp, 1976; Williams et al., 1977; Schmidt-Koenig and Keeton, 1978].

Summarized reports in the literature on various effects of exposure of insects to RFR indicated the effects ranged from unrest to death, depending on the level and duration of the exposure and the species studied. In laboratory studies, abnormal development of beetle pupae was reported at power densities and exposure durations that produced significant heating. In a recent study [Westerdahl and Gary, 1981], adult honeybees were exposed to 2.45 GHz CW RFR at power densities from 3 to 50 mW/cm$^2$ for durations of 0.5 to 24 h. The bees then were held in an incubator for 21 days to determine their consumption of sucrose syrup and to observe mortality, if any. No significant differences were found between RFR-exposed and sham-exposed or control bees. In another study, it was found that foraging-experienced honeybees retained normal flight, orientation, and memory functions after exposure to 2.45 GHz CW RFR at power densities from 3 to 50 mW/cm$^2$ for 30 min.

In summary, no significant biological effects on airborne fauna are expected from exposure to the main beam of the 1-MW DSS-14 transmitter. At most, only a few airborne individuals of fauna common to the area might be affected in a localized area near the system, and even these effects may not be hazardous. A detailed discussion of the biological effects considered in the preparation of this EA is presented in Appendix C.

## C.   POSSIBLE PHYSICAL ENVIRONMENTAL EFFECTS

### 1.   Introduction

Operation of the upgraded DSS-14 antenna at the Mars Site at the GDSCC at a power level of 1 MW not only will add RFR energy to the ambient RFR field, but it also could affect other devices that operate with electromagnetic systems: radio, television, other radars, cardiac pacemakers, electroexplosive devices, and fuel-handling processes.

Any changes in the ambient electromagnetic field brought about by the antenna's operation, however, would take place at the frequency of operation (8.51 GHz) and would only last for the duration of transmission time (seconds to minutes).

Additionally, the beams emitted by the 1-MW DSS-14 antenna are spatially restricted. The main beam, which contains most of the RFR power, can be pointed at an angle ranging from 10 deg to 89 deg above the horizon. In contrast, the concentrations of RFR power in the beam's sidelobes are insignificant as compared to the main beam.

## 2. Effects Upon Cardiac Pacemakers

A common electromagnetic device, now carried by an increasing number of people, is a cardiac pacemaker. In a 1975 draft standard by the Association for the Advancement of Medical Instrumentation [AAMI-STD, 1975], a design susceptibility threshold of 200 V/m (electric field equivalent to a power density of 10 mW/cm$^2$) was suggested for the safety of cardiac pacemakers.

Since then, newer models of cardiac pacemakers have been tested against electromagnetic signals very similar to those that are to be radiated by the 1-MW radar transmitter. Most of these newer models are unaffected by electric fields that are as high as 330 V/m. Thus, this safe value is greater than the 200 V/m that would be measured at ground level at all points outside the site boundary of the DSS-14 antenna.

So, the new 1-MW radar transmitter does not pose a threat to people on the ground who are fitted with cardiac pacemakers with a susceptibility threshold of 200 V/m. The calculated RFR levels to be expected from the 1-MW transmitter are well below those to which current models of cardiac pacemakers are shielded.

RFR-illumination of aircraft is not expected to constitute a hazard to people flying that are wearing pacemakers because exposure of aircraft to the main beam will be prohibited.

## 3. Effects Upon Electroexplosive Devices (EEDs)

The USAF has a standard for determining safe separation distances between radars and areas where EEDs are stored, handled, or transported. This USAF Standard, however, is based on the emission of conventional radars, which differ so greatly from those of the upgraded 1-MW DSS-14 transmitter that unquestioned adherence to the standard might result in the determination of "safe" separation distances that would actually not be safe. No ordnance handling operations, however, are expected to be performed in the vicinity of the 1-MW DSS-14 antenna.

## 4. Effects Upon Fuel-Handling Operations

The USAF Technical Manual TO-31Z-10-4 [USAF, 1987], with its information about electromagnetic radiation hazards, indicates that fuel-handling operations (fueling of aircraft, etc.) should not be undertaken in electromagnetic fields with pulse power greater than 5,000 mW/cm$^2$. Since no fuel-handling operations are planned inside the site boundary of the 1-MW DSS-14 antenna, no fuel-handling hazard will be faced. Outside of the site boundary, power levels are well below the USAF Standard.

Thus, no adverse biophysical or socioeconomic effects are anticipated from the upgrading of the power level of the DSS-14 radar transmitter from 0.5 MW to 1 MW.

SECTION V

THE GOLDSTONE DEEP SPACE COMMUNICATIONS COMPLEX


A.    LOCATION OF THE GOLDSTONE DEEP SPACE COMMUNICATIONS COMPLEX (GDSCC)

    The GDSCC is located in southern California, in a natural, bowl-shaped depression area in the Mojave Desert, in San Bernardino County about 64.5 km (40 mi) north of Barstow, California, and about 258 km (160 mi) northeast of Pasadena, California, where JPL is located.

    As indicated in Section I, the GDSCC is part of the NASA's Deep Space Network (DSN), one of the world's larger and more sensitive scientific telecommunications and radio navigation networks. The GDSCC is managed, technically directed, and operated for NASA by JPL.

    The 135-km$^2$ (52-mi$^2$) GDSCC lies within the western part of the Fort Irwin Military Reservation (Figure 2). A Use Permit for the land was granted to NASA by the U.S. Army. The GDSCC is bordered by the Fort Irwin Military Reservation on the north, east, and southeast; the China Lake Naval Weapons Center on the northwest; and the State and Federal lands managed by the U.S. Bureau of Land Management (BLM) on the south.


B.    FUNCTIONS OF THE GDSCC

    After the Space Act of 1958 had accelerated U.S. plans and programs for space exploration, JPL initiated construction work at Goldstone to build the first tracking station of what is now known as the DSN. Thus, for more than three decades, the primary purpose of the DSN has been and continues today to support the tracking of both manned and unmanned spacecraft missions and to provide instrumentation for radio and radar astronomy in the exploration of the solar system and the universe.

    Over the years, the DSN has become a world leader in the development of low-noise receivers; tracking, telemetry, and command systems; digital signal processing; and deep-space radio navigation.

    The basic responsibilities of the DSN are to receive telemetry signals from spacecraft, to transmit commands that control the various spacecraft operations, and to generate the radio navigation data to locate and guide the spacecraft to its destination.

    Because of its advanced technical ability to perform the above services, the DSN also is able to carry out the following functions:  flight radio-science, radio and radar astronomy, very long baseline interferometry (VLBI), precise measurement of minute earth movements (geodynamics), and participation in NASA's Search for Extraterrestrial Intelligence (SETI).

    The GDSCC also is an R&D center both to extend the communication range and to increase the data acquisition capabilities of the DSN. It serves as a proving ground for new operational techniques. Prototypes of all new equipment are thoroughly tested at the GDSCC before they are duplicated for installation at overseas stations (see Section V.C).

KINGS CANYON
NAT'L PARK

DEATH VALLEY
NAT'L MONUMENT

-N-

395

95

INYO CO.

Nevada
California

Las Vegas

SEQUOIA NAT'L PARK

TULARE CO.

15

CHINA LAKE NAVAL
WEAPONS CENTER

FORT IRWIN

95

KERN CO.

GOLDSTONE
DSCC

58

SAN BERNARDINO CO.

Barstow

40

395  15

EDWARDS
AIR FORCE BASE

Victorville

TWENTYNINE PALMS
MARINE CORPS BASE

LOS ANGELES CO.

PASADENA

San Bernardino

Los Angeles

JOSHUA TREE
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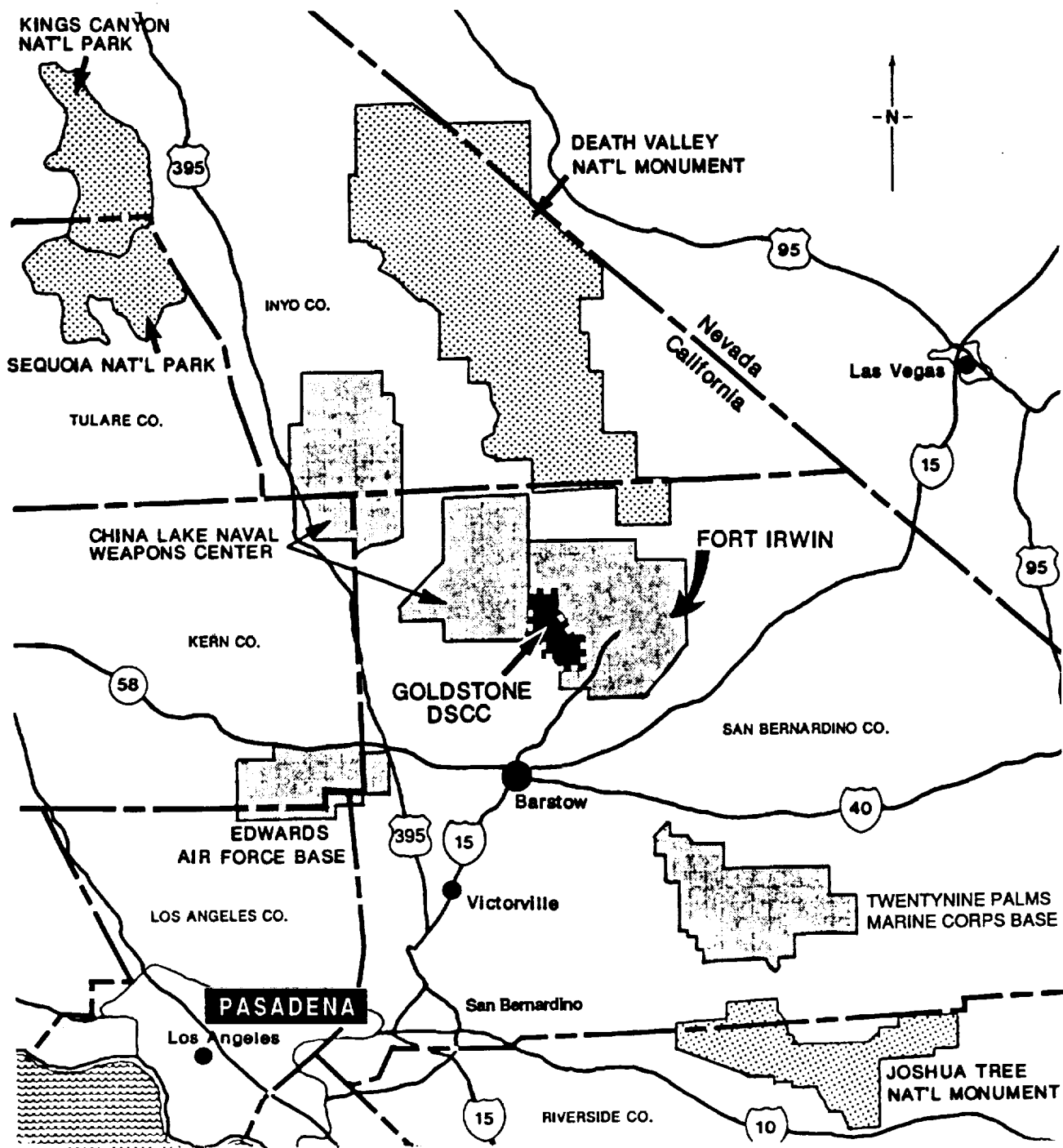
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Figure 2.    Geographic Relationship of the Goldstone Deep Space Communications
Complex (GDSCC) to JPL in Pasadena. California

5-2

C.    FACILITIES AT THE GDSCC

     The GDSCC is a self-sufficient, working community with its own roads,
airstrip, cafeteria, electrical power, and telephone systems, and it is equipped
to conduct all necessary maintenance, repairs, and domestic support services.
Facilities at the GDSCC include about 100 buildings and structures that were
constructed during a 30-yr period from the 1950s through the 1980s.  The
construction of additional buildings and structures continues today as the
GDSCC increases its activities and operations.

     Goldstone is one of three Deep Space Communications Complexes (DSCCs)
operated by NASA.  The three DSCCs are located on three continents:  at
Goldstone in southern California's Mojave Desert; in Spain, about 60 km (37 mi)
west of Madrid at Robledo de Chavela; and in Australia, near the Tidbinbilla
Nature Reserve, about 40 km (25 mi) southwest of Canberra.  Because these three
DSCCs are approximately 120 deg apart in longitude, a spacecraft is nearly
always in view of one of the DSCCs as the Earth rotates on its axis (Figure 3).

     Activities at the GDSCC support six parabolic dish antennas at five sites
called Deep Space Stations (DSSs):  Four sites are operational for space mis-
sions, while one is devoted to R&D activities.  There also are four, similar,
operational DSSs in Spain and in Australia.  Thus, the NASA DSN consists of a
worldwide network of 12 operational DSSs.

     The GDSCC also includes three antennas at the Venus Site (for R&D), while
another parabolic dish antenna at the Mojave Base Site is operated by the
National Oceanic and Atmospheric Administration (NOAA).

     A Network Operations Control Center (NOCC), located at JPL in Pasadena,
controls and monitors the DSN.  A Ground Communications Facility (GCF) of the
DSN operates to link together the NOCC at JPL with the three DSCCs at Goldstone,
Spain, and Australia.

     A 26-m (85-ft) antenna, located at the Pioneer Site, was deactivated in
1981.  In 1985, the Pioneer antenna (DSS 11) was designated a National Historic
Landmark by the U.S. Department of Interior, and the Pioneer Site was returned
to the U.S. Army.  Each of the Goldstone sites is briefly described in Section
V.D.

     Total NASA/JPL facilities at the GDSCC (Figure 4) include the six DSN
parabolic dish antennas, an airport, a microwave test facility, miscellaneous
support buildings, and a remote support facility in Barstow, California, located
about 64.5 km (40 mi) south of the GDSCC.  The GDSCC support staff consists of
about 260 personnel on-site and at the Barstow facility.  Table 4 summarizes the
major facilities, buildings (number and square footage), and antennas (construc-
tion date and size).  Three sites within the GDSCC have antennas (referred to as
stations) devoted to NASA DSN operations:  Echo Station, Mars Station and Uranus
Station, and two antennas at the Apollo Station.  Two other sites have antennas
devoted to R&D:  Venus, operated by the GDSCC, and Mojave, operated by NOAA.


D.    ANTENNA STATIONS AT THE GDSCC

     1.   Echo Site (DSS 12)

     The Echo Site, as the administration center and operations
headquarters of the GDSCC, is the most extensively developed site on the
complex.  It has one 34-m (111.5-ft) antenna and 24 support buildings, with a
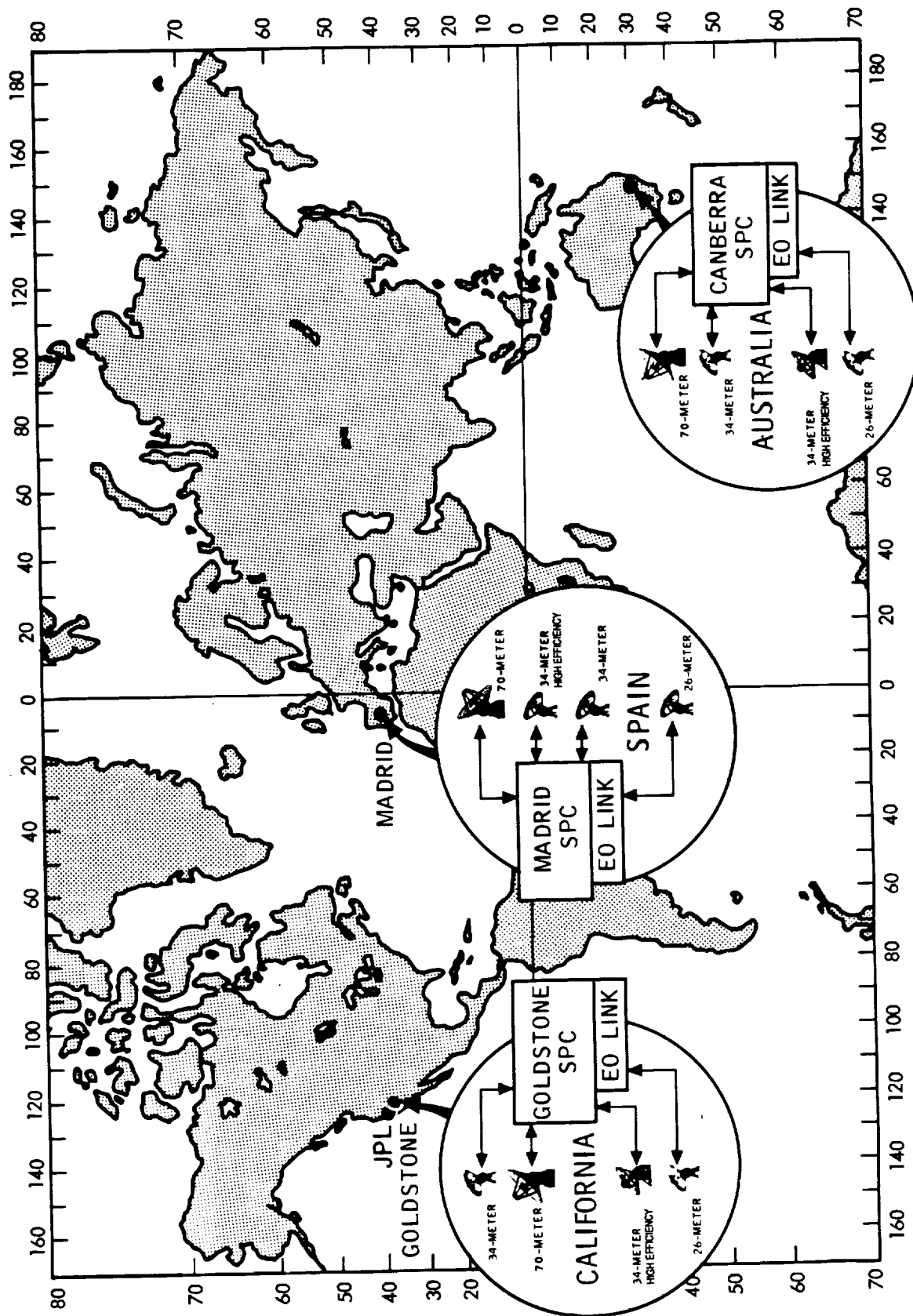
Figure 3. The Three-Continent NASA Deep Space Network as It Exists in 1992
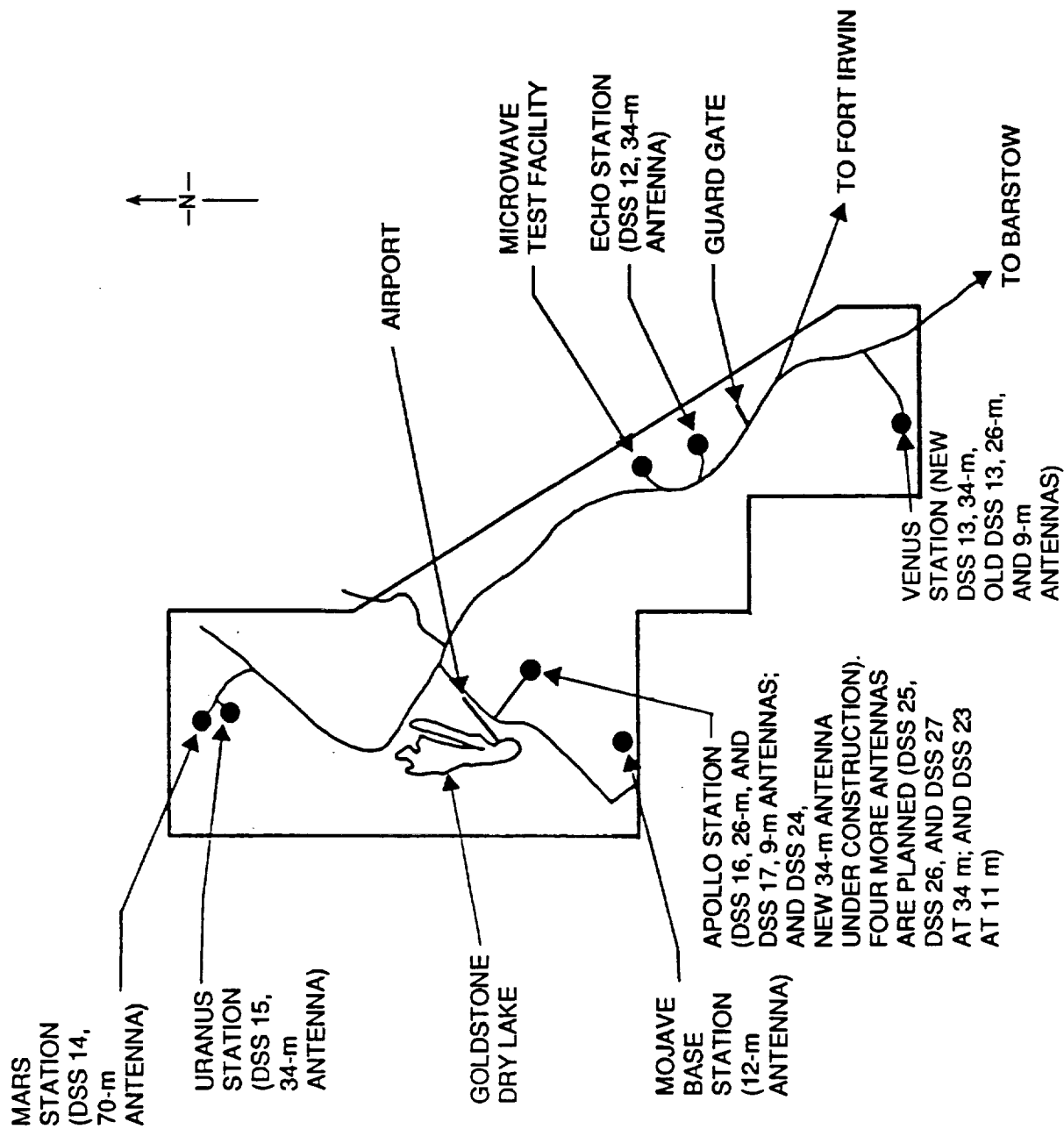
Figure 4. Schematic Map of the GDSCC Showing Locations of the Five NASA Deep Space Stations (DSSs) and the Mojave Base Station Operated by NOAA

Table 4.  Major Facilities at the GDSCC

| Size | Station Number | Buildings Number | Buildings (ft$^2$)[a] | Antennas Date of Construction | Antennas Size (meters) |
|------|----------------|------------------|-----------------------|-------------------------------|------------------------|
| Echo Site | — | 25 | 79,208 | — | — |
| | DSS 12 | — | — | 1961[b] | 34[c] |
| Venus Site | — | 15 | 12,589[d] | — | — |
| | DSS 13 (new) | — | — | 1991 | 34 |
| | DSS 13 (old) | — | — | 1962[e] | 26 |
| | Existing antenna (no number assigned) | — | — | — | 9 |
| Mars Site | — | 14 | 41,754 | — | — |
| | DSS 14 | — | — | 1966/1988 | 70[f] |
| | DSS 15 | — | — | 1984 | 34 |
| Apollo Site | — | 21 | 43,978 | — | — |
| | DSS 16 | — | — | 1965[g] | 26 |
| | DSS 17 | — | — | — | 9 |
| | DSS 24[h] (under construction) | — | — | — | 34 |
| Mojave Site | — | 5 | 11,850 | 1964 | 12[i] |
| Airport[j] | — | 3 | 4,848 | 1963/1970 | — |
| Microwave Test Facility | MTF | 1 | 2,880 | 1963 | — |
| Miscellaneous | — | 3 | 1,430 | — | — |
| Barstow Facility[k] | — | 1 | 28,343 | — | — |

[a]To convert square feet into square meters, multiply by 0.09290.

[b]The original antenna, built in 1959, was moved to the Venus Site in 1962.
A 26-m antenna, built in 1961, was extended to 34 m in 1978.

[c]This antenna is to be dismantled and removed after the planned DSS-24 antenna at the Apollo Site becomes operational in 1993.

[d]This square footage does not include the two newly constructed facilities for Hazardous Materials Storage and for Acid Wash.

[e]This antenna was constructed at the Echo Site in 1959; moved to the Venus Site in 1962.

[f]Originally constructed as a 64-m antenna in 1966; enlarged to a 70-m antenna in 1988.

[g]This antenna originally was constructed for the NASA Goddard Space Tracking and Data Network.  JPL/GDSCC/DSN operation of the antenna began in October 1984.

[h]This planned DSS-24 antenna previously was designated as DSS-18.  Four new antennas are now planned for the Apollo Site:  DSS 23, 11 m; and DSS 25, DSS 26, and DSS 27 all at 34 m.

[i]This antenna is operated by the National Oceanic and Atmospheric Administration (NOAA).

[j]The airport is located at the Goldstone Dry Lake.

[k]This site, a leased facility, is located in Barstow, California, about 64.5 km (40 mi) southwest of the GDSCC.

Source:  *Directory of Goldstone DSCC Buildings and Supporting Facilities (Gold) Book*, [JPL, 1989a].

combined area of 7,358 m$^2$ (79,208 ft$^2$). Support buildings include administration and engineering offices, cafeteria, dormitory, transportation and maintenance facilities, storage areas, and warehouses. The Echo Station originally was built in 1959 as a 26-m (85-ft) antenna. The antenna was first used in 1960 to support the Echo Project, an experiment to transmit voice communications coast-to-coast by bouncing radio signals off the reflective Mylar surface of a passive balloon-type satellite. In 1962, this original 26-m antenna was moved to the Venus Site. In anticipation of this move, a newer 26-m antenna had been built at the Echo Site in 1961. In 1978, this antenna was enlarged to 34 m (111.5 ft). The present antenna is approximately 35 m (113 ft) high and weighs about 270,000 kg (300 tons). In 1993, it is to be replaced by the new DSS-24 34-m antenna that is under construction at the Apollo Site.

## 2. Venus Site (DSS 13)

The Venus Site consists of three antennas: DSS 13, a new 34-m (111.5-ft) antenna, a 26-m (85-ft) antenna, and a 9-m (29.5-ft) antenna. The smaller antenna is no longer used. There are 15 buildings with a combined area of 1,170 m$^2$ (12,589 ft$^2$). The support buildings provide space for operations control, laboratories, offices, security, workshops, warehouses, and mechanical equipment. The 26-m antenna, which was originally located at the Echo Site, was moved to the Venus Site in 1962. The antenna was used for a radar astronomy study of the planet Venus. Currently, its primary functions are R&D and performance and reliability testing of high-power radio-frequency transmitters and new systems and equipment prior to their introduction into the DSN.

The newly constructed DSS-13 antenna, a 34-m (111.5-ft) antenna similar in size and structure to DSS 15 (see below), began operation with R&D activities in 1991. It is to functionally replace the older 26-m antenna. An EA concerning this new DSS-13 antenna is the subject of JPL Publication 87-4, Vol. 6 [JPL, 1988b].

## 3. Mars Site (DSS 14 and DSS 15)

The Mars Site consists of two antennas at two stations (the Mars and Uranus stations) and 14 buildings, with a combined area of 3,879 m$^2$ (41,754 ft$^2$). The support buildings provide facilities for operations control, offices, training, mechanical equipment, storage, and security. In May 1989, M. B. Gilbert Associates (MBGA), Long Beach, California, submitted an Environmental Assessment to JPL concerning the construction work needed for a proposed building extension to the Operations Building (Bldg. G-86) at the Mars Site.

JPL Publication 87-4, Vol. 11 [JPL, 1990b] is an expanded JPL-version of the Environmental Assessment document submitted to JPL by MBGA in May 1989.

The Mars Station antenna (DSS 14), at 70 m (230 ft) in diameter, is one of the larger antennas of its kind in the world (see front cover). In 1991, the antenna celebrated its 25th anniversary of operation. The antenna, which originally was constructed as a 64-m antenna in 1966 and was enlarged to a 70-m antenna in 1988, is 7.25 times more powerful and sensitive than a 26-m antenna, extending the range of deep-space communications by 2.7 times. It can maintain communications with spacecraft to the edge of the solar system. Standing more than 235 ft high, this antenna is one of the more striking features to be seen in the GDSCC geographic area. The 70-m antenna was used in August 1989 for the Voyager 2 spacecraft's encounter with the planet Neptune. The latter is located at a distance of 4.5 billion km (2.8 billion miles) from Earth.

The Uranus Station (DSS 15) has a 34-m (111.5-ft) high-efficiency (HEF) precision-shaped antenna, located approximately 488 m (1,600 ft) southeast of the Mars Station antenna. Built in 1984, this antenna at the GDSCC first was used in January 1986 to support the encounter of the Voyager 2 spacecraft with the planet Uranus. The latter is located at a distance of more than 3 billion km (1.8 billion miles) from Earth. The newly constructed 34-m, precision-shaped antenna at the Venus Site (see above) and the DSS-24 antenna under construction at the Apollo Site (see below) are similar in size and structure to this Uranus Station antenna.

    4.   Apollo Site (DSS 16, DSS 17, and DSS 24)

    The Apollo Site has a 26-m (85-ft) antenna (DSS 16), a 9-m (29.5-ft) antenna (DSS 17), and 21 buildings, with a combined total area of 4,086 m$^2$ (43,978 ft$^2$). The buildings provide space for operations, equipment, storage, and warehousing. The 26-m antenna originally was constructed in 1965 by NASA's Goddard Space Tracking and Data Network to support the manned Apollo missions to the Moon. Operation of this antenna under JPL management began in October 1984. Both the 26-m and the 9-m antennas now are used to support the missions of the Space Shuttle [Space Transportation System (STS)] and satellites in both low and high Earth orbits. In May 1989, M. B. Gilbert Associates, Long Beach, California, submitted an EA to JPL concerning the construction work needed for a planned new 34-m (111.5-ft) antenna (DSS 24) at the Apollo Site[1]. The details of this EA are described in JPL Publication 87-4, Vol. 10 [JPL, 1990a]. This DSS-24 antenna now is under construction. Four more antennas are planned to be constructed at the Apollo Site: DSS 23 at 11 m; and DSS 25, DSS-26, and DSS 27, all at 34 m.

    5.   Mojave Base Site (NOAA Antenna)

    The Mojave Base Site has one antenna and five buildings, with a combined area of 1,100 m$^2$ (11,850 ft$^2$). At one time, these buildings provided support facilities for operations, equipment, and maintenance. Except for the NOAA operations buildings, however, these buildings now are not in use.

    The Mojave Base Site has a 12-m (40-ft) antenna operated by NOAA. The antenna is involved in several programs, including monitoring of shifts in the Earth's tectonic plates, monitoring weather changes, and retrieving information from very low-orbiting Earth satellites.


E.   SUPPORT FACILITIES AT THE GDSCC

    1.   Goldstone Dry Lake Airport

    The airport consists of an approximately 1,829-m X 31-m (6,000- X 100-ft) paved runway. There are two buildings at the airport site neither of which is presently in use. An open hangar is used to provide shelter for a single aircraft. For its personnel, NASA operates three scheduled shuttle flights per week to the GDSCC that originate from the Burbank-Glendale-Pasadena airport. In addition, the Goldstone airport is used infrequently by administrative U.S. Army flights. Both NASA and the U.S. Army use propeller-driven aircraft.

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[1] This planned DSS-24 antenna previously was designated as DSS-18.

2. Microwave Test Facility and Fire-Training Area

The Microwave Test Facility (MTF) and Fire-Training Area consist of a single building of 268 m$^2$ (2,880 ft$^2$) along with areas identified for fire fighting. The MTF is used for R&D testing of antenna microwave equipment. Fire training includes procedures for the quenching of fires.

3. Miscellaneous Buildings in the GDSCC Area

Three buildings and structures at the GDSCC that fall into this category include the main gate house, pump house, and radio spectrum monitor. The total area of these three buildings/structures is 133 m$^2$ (1,430 ft$^2$).

4. Off-Site Facility at Barstow, California

In addition to the above-mentioned on-site facilities, the GDSCC leases an office and warehouse support facility. The facility is a single-story, 2,633-m$^2$ (28,343-ft$^2$) structure located at 850 Main Street, in the nearby city of Barstow.

F.    NONSTRUCTURAL SUPPORT FACILITIES AT THE GDSCC

1. Transportation Network

The major roadways in the area are shown in Figure 5. The only surface public transportation route to the GDSCC is by the Fort Irwin Road that leads to Fort Irwin. The NASA Road cutoff from Fort Irwin Road leads into the GDSCC. The NASA Road merges with Goldstone Road, which is the only north-south paved access road within the complex. Both the NASA and Goldstone Roads are paved two-lane roads and are maintained by the Fort Irwin Post Engineer. Two-lane paved access roads also lead to each of the sites and major facilities.

2. Utilities and Services

The Southern California Edison Company provides electricity for the Goldstone Complex. The GDSCC provides its own backup diesel-engine generators to ensure operations during emergencies and continuity of electrical service for prescheduled periods of time. Gasoline, diesel oil, and hydraulic oil are stored in double-walled underground storage tanks (USTs) fitted with sensors between the walls to detect leaks. Water is supplied by Fort Irwin from groundwater basin wells. Sanitary sewage is discharged through septic tank systems to leaching fields. The Echo and Mars Sites discharge wastewater to evaporation ponds (see JPL Publication 87-4, Vol. 8 [JPL, 1989a]).

G.    SOLID-WASTE MANAGEMENT FACILITIES AT THE GDSCC

At the Echo Site, the GDSCC operates its own 4.05-hectare (10-acre), Class-III solid-waste landfill. This facility accepts only nonhazardous, solid wastes.

Most of a small quantity of hazardous waste, generated at the GDSCC each year, is sent to off-site commercial facilities for reclamation and eventual reuse. The remainder is transported to off-site commercial treatment or disposal facilities within 90 days of generation. The GDSCC now has four, new, properly managed storage facilities for hazardous materials and wastes: one is located at the Echo Site, one at the Venus Site, and two at the Mars Site. The
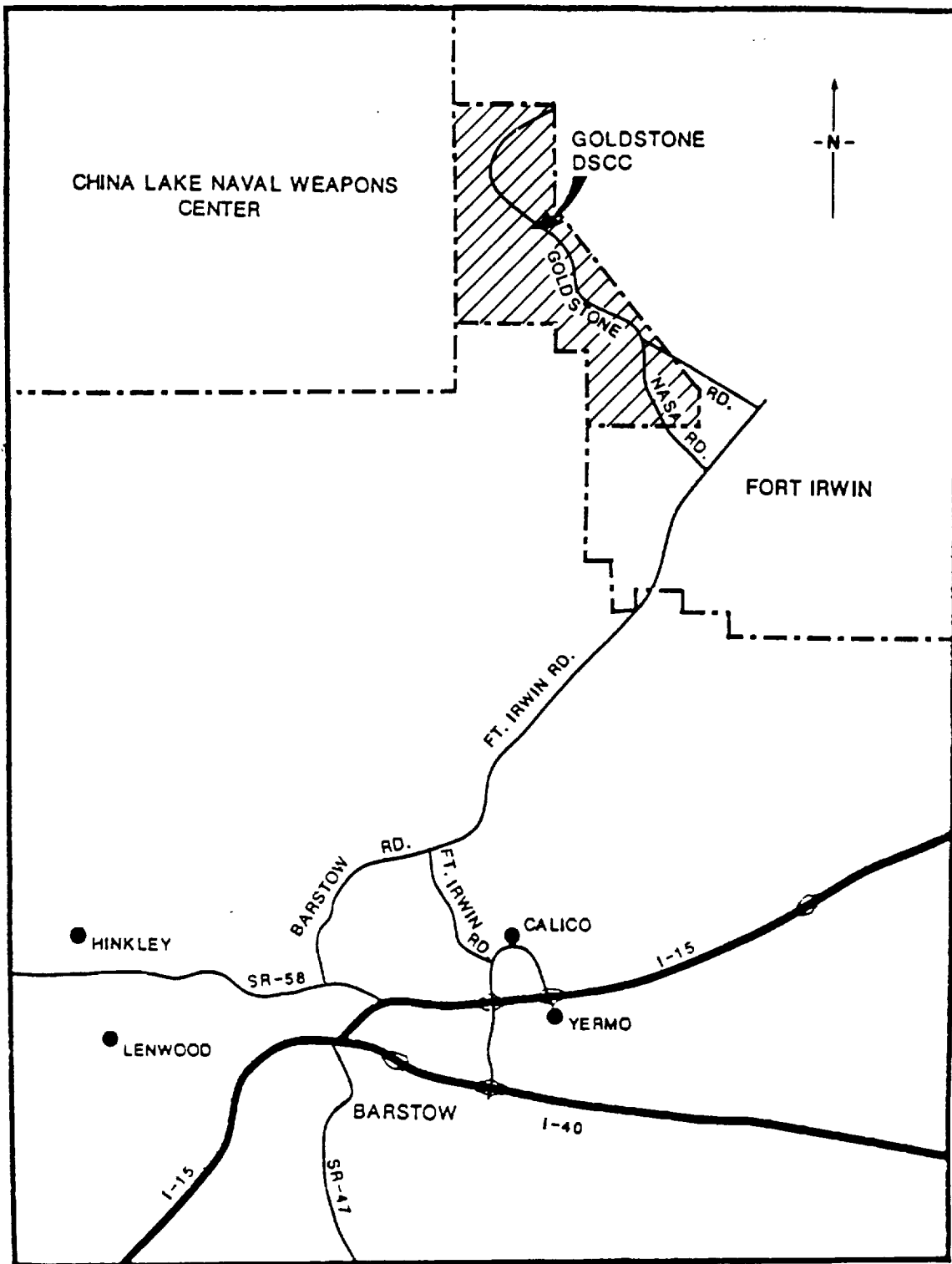
Figure 5. Major Roads Leading to and at the GDSCC

GDSCC does not operate any facilities that require a hazardous waste permit.
Details concerning the construction of the two new storage facilities for
hazardous materials and wastes at the Echo and Venus Sites are described in
JPL Publication 87-4, Vol. 9 [JPL, 1989b]. Two more storage facilities for
hazardous materials and wastes, one at the Mars Site and the other at the Apollo
Site, were completed in 1990. In accordance with its environmental management
program, the GDSCC conducts all of its waste-management operations in strict
compliance with environmental regulations, in a manner consistent with
protection of human health and the environment.


H.    WASTEWATER MANAGEMENT FACILITIES AT THE GDSCC

    Four functioning sewage evaporation ponds, one pair at the Echo Site and
another pair at the Mars Site, are designed to receive effluent from an upstream
septic tank system. Extensive work was completed in the spring of 1989 to
repair and reshape the previously eroded embankments of the wastewater
evaporation ponds. Details of this construction work are recorded in JPL
Publication 87-4, Vol. 8 [JPL, 1989a].


I.    UNDERGROUND STORAGE TANKS (USTs) AT THE GDSCC

    As a large-scale facility located in a remote, isolated desert region, the
GDSCC operations to support the various DSS-antennas require numerous on-site
storage facilities for gasoline, diesel oil, hydraulic oil, and waste oil. The
most environmentally safe and economical way to store large quantities of these
liquids is in double-walled, steel shells with outer fiberglass coating for
corrosion protection, and a monitoring system in the annular space between the
inner and outer shells to detect any leaks from either shell.

    The installation of 13 new USTs with the above-described, environmentally
safe properties (7 at the Echo Site, 5 at the Mars Site, and 1 at the Mojave
Base Site) is discussed in detail in JPL Publication 87-4, Vol. 13 [JPL, 1991].

    The removal of soil that had been contaminated by leakage from some of the
old USTs is discussed in detail in JPL Publication 87-4, Vol. 14 [JPL, 1992].


J.    OPERATIONAL RELATIONSHIPS BETWEEN THE GDSCC AND FORT IRWIN

    Because the GDSCC is located within the Fort Irwin property, the two
installations potentially can affect each other's roles and missions.
Fort Irwin is a U.S. Army installation serving as the U.S. Army National
Training Center (NTC). The remote desert environment allows military task
forces to practice large-scale training maneuvers that could affect natural,
historic, and cultural resources at the GDSCC. This especially is true when the
maneuvers involve the movement of heavy equipment (tanks, large trucks) within
the GDSCC. Most maneuvers occur at the eastern border of the GDSCC, and every
effort is made by both the GDSCC and Fort Irwin personnel to avoid the use of
sensitive areas for such maneuvers.

K.    NATURAL ENVIRONMENTAL ASPECTS OF THE GDSCC

    1.    Geology

        The GDSCC is located in the North Central section of the Mojave
Desert Province.  Typically, the Mojave Desert Province consists of broad, flat
plains separated by low mountains [305 to 610 m (1,000 to 2,000 ft) of
topographic relief].  The GDSCC is situated within one of these low mountain
areas.

        The GDSCC is located in a naturally occurring bowl-shaped depression area
bounded on three sides by geological faults.  The Garlock Fault lies to the
north, while the Blackwater and Calico Faults lie, respectively, to the west and
south.  The GDSCC is bounded on the east by the Tiefort Mountains.  Each antenna
site at the GDSCC is located on natural alluvial material, ranging in thickness
from 4.6 m (15 ft) at the Venus Site to more than 21.3 m (70 ft) at the Echo
Site.  The alluvium is derived from the surrounding hills.

    2.    Hydrology

        Groundwater in the Goldstone area is generally confined and is found
at depths ranging from 51.8 m (170 ft) near the Minitrack Site to approximately
305 m (1,000 ft) below the Echo Site.  Chemical analyses of the groundwater have
yielded total dissolved solids (TDS) values in excess of 1,000 ppm, indicating
that the groundwater is brackish.  The Goldstone Complex currently obtains
potable water form a group of wells located at Fort Irwin, approximately
16.09 km (10 mi) to the southeast.

    3.    Climatic Conditions

        The GDSCC lies within the U.S. Naval Weather Service's Southwest
Desert, Climatic Area A.  Mean annual temperatures for the area range from 10 to
26.7°C (50 to 80°F).  Temperatures can climb as high as 45.5°C (114°F) during
the summer months, and drop as low as -11.7°C (11°F) during the winter months.
Mean annual precipitation for the area is approximately 6.35 cm (2.5 in.); most
precipitation falls between November and February.

# SECTION VI

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# SECTION VII

## CERTIFICATION

I hereby certify that all work performed by Battelle Pacific Northwest Laboratories, Richland, Washington, in its environmental assessment of the possible radio frequency radiation hazards and interferences to be expected from upgrading of the power level of the DSS-14 radar transmitter from 0.5 MW to 1 MW at the Mars Site at the Goldstone Complex of the Fort Irwin Military Reservation, San Bernardino County, California, as described in this report, was performed in compliance with Federal, State, and local regulations, and in accordance with good engineering and investigative practice.

Leonard H. Kushner
Registered Professional Engineer


Signature _____

Date Signed: _____October 15, 1992_____

Registration No.   E9003, Electrical          State: California
                   SF1086, Safety                    California
                   REA00078 Environmental Assessor   California


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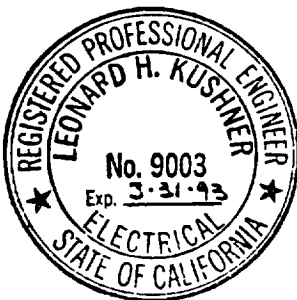
APPENDIX A


THEORETICAL ANALYSIS OF THE MICROWAVE RADIATION LEVELS
FROM THE PROPOSED UPGRADE TO 1 MEGAWATT OF THE
DSS-14 TRANSMITTER AT THE 70-METER MARS ANTENNA AT THE GDSCC


(The text and illustrations in this Appendix
were provided to JPL
by Battelle Pacific Northwest Laboratories,
Richland, Washington)

APPENDIX A


THEORETICAL ANALYSIS OF THE MICROWAVE RADIATION LEVELS FROM THE PROPOSED
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## A.1 INTRODUCTION

This Appendix provides details of the methodology used to calculate
levels of microwave power density arising from the upgrade of the 70 meter
MARS antenna to 1 MW of input power both at the DSS-14 site and in the
environment surrounding it. The calculations were performed for a 70 meter
diameter microwave dish operating at a frequency of 8.51 GHz with an input
power of 1 MW. Calculations are based on antenna data supplied by JPL. The
physical and electrical characteristics of the antennas were also obtained
from JPL. The Ohio State University Numerical Electromagnetic Reflector
Antenna Code (NEC-REF) (Ruddick and Chang 1982) was used for all calculations.
Additional information about antenna quadrapod dimensions for the 70 meter
antenna to best fit the NEC-REF model was obtained from Dan Bathker of JPL by
telephone and plotted as in Figure A.1.


## A.2 DESCRIPTION OF ANALYSIS

This analysis is based on the technical information provided by JPL and
the use of the NEC-REF. This code is capable of calculating the power density
in both the near and far field zones for any parabolic reflector antenna of
general rim shape, taking account of blockage of the main reflector aperture
by the feed system and supporting structures. The aperture distribution
source may be specified in many different ways such as (1) feed horn type and
dimensions, (2) feed horn aperture distribution, (3) feed horn pattern
(theoretical expression or specified numerical pattern) or (4) reflector
aperture distribution. The code installed on a microVAX II computer is
capable of calculating the fields at any location from as close as one antenna
dish diameter out to an unlimited distance. However, the 70 meter diameter
JPL antenna actually consists of shaped subreflectors and main reflectors that
do not correspond to true classical conical shapes so the wavefront leaving
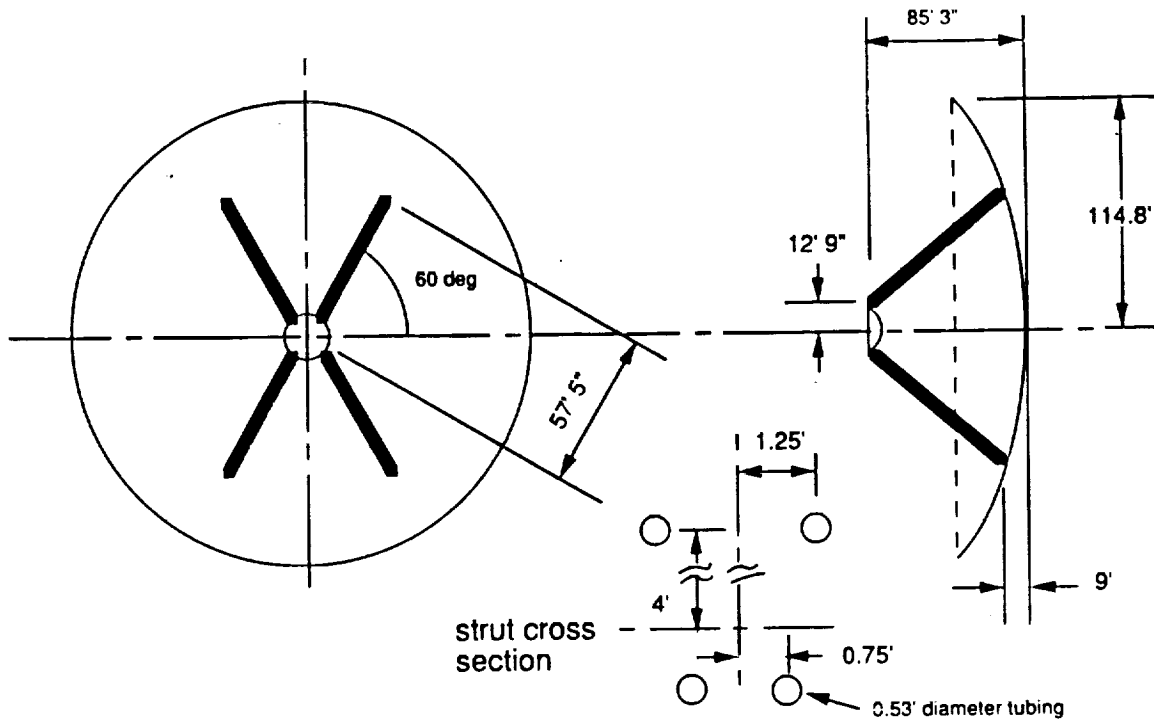
**FIGURE A.1.** Assumed Position and Dimensions of Struts on 70-meter-
diameter Mars Antenna (not to scale)

the subreflector is not truly spherical as for hyperboloidal subreflectors. The shaped main reflectors were designed to "patch up" the intentionally "distorted" amplitude and phase pattern leaving the subreflector. Thus the antenna characteristics given had to be modified to allow the NEC-REF code, based on conic reflectors, to best approximate the radiation patterns for the JPL non-conic reflectors. This was accomplished by modifying the feed characteristics of the JPL antennas so that main reflector aperture distributions in the NEC-REF model were equivalent to those specified or estimated for the JPL shaped antennas. However, the sources had to be modified in such a way that the spill-over and side radiation from the feed system was not reduced in any way so that "worst case" estimates of radiation from the JPL sources were not compromised. Since the purpose of this analysis is to ensure that people and the environment will not be overexposed to microwave radiation the analysis is intentionally directed toward quantifying worst case radiation levels. Where there is conflicting data, worst case values have been intentionally chosen for the analysis. Since the proposed JPL antennas are of the

Cassegrainian type (consisting of a primary feed, a subreflector, and a main reflector), the NEC-REF-code designed for a primary feed and reflector only could not be used in one pass to determine the radiation levels. However, Rusch (1963) has published a paper with equations that were programmed in this study to calculate the fields for a combination of a primary feed pattern and a hyperboloidal subreflector. Ground reflections were taken into account by assuming that perfectly reflected fields always added directly with the incident fields at each location near the ground to produce the highest possible power density of 4 times the incident power density. Thus, situations where reflections partially canceled incident radiation were ignored. The final "worst case" approximations result from an inherent deficiency in the NEC-REF software. Though the code is stated to have the capability for both near-field and far-field computations for reflector antennas with paraboloidal surfaces, it was found in this analysis that the inclusion of commands for feed blockage and strut scattering resulted in excessively high calculated power densities on the beam axis and some higher than expected very narrow side lobes off the beam axis. A discussion with the author of the NEC-REF, Dr. Roger Ruddick, revealed that the expression for radiation contributions from the blockage and strut scattering was based on a far-field analysis for those structures. Thus, even though the analysis for the main reflector was valid for the near-field, the analysis including the substructures could give pessimistically high level contributions to the total power density if one were in the near-field zones of such structures. This is certainly the case even at great distances from the JPL antenna because of the large size of the substructures of the antenna. In order to ensure that the calculations near ground where personnel can be exposed represent truly "worst case" values it was necessary to include the feed blockage and strut scattering in the analysis. All of the above assumptions ensure that the analysis results in a "worst case" prediction of the highest expected power density levels. The general theory for this analysis is discussed in Appendix B.

## A.3 NEC-REF MODELS

The modeling of the feed system of the 70 meter antenna was accomplished in the following manner:

1. The circular waveguide feed pattern provided by Dan Bathker of JPL was modified over the portion that would be reflected by the subreflector so that it would result in uniform exposure of the main reflector to within 1 meter from the rim and taper down by -13 db at the rim. The shape of the remaining portion of the directivity pattern was retained but the gain corrected to account for modification of the pattern illuminating the subreflector.

2. The modified directivity pattern was assumed to illuminate the subreflector and the combined pattern was determined by the method of Rusch (1963).

3. The combined pattern was entered into the NEC-REF as the feed pattern for calculating power densities.

## A.4  CALCULATED RESULTS

The NEC-REF Code was used to calculate the equivalent plane wave power densities at various locations around the 70 meter antenna. Calculations of power density were made at 6 feet above the ground directly under the main beam and at different distances from and parallel to the center of the main beam. All calculations of power density near ground were made for different elevation angles of the main beam varying from 0° to 60°. A beam azimuthal direction of 315° with respect to true north, which corresponds to the direction of maximum ground gradient resulting in "worst case" calculated ground level power densities, was used for most of the calculations. The calculated power densities at 6 feet above the ground were for characterizing "worst case" exposure levels for ground personnel and terrestrial biota, while those made for various distances near the main beam were for characterizing "worst case" exposures of aircraft and airborne biota.

## A.5  CALCULATED POWER DENSITIES RESULTING FROM MICROWAVE RADIATION ASSOCIATED WITH THE 70 METER MARS ANTENNA

Power densities calculated under the main beam of the 70 meter antenna are shown in Figures A.2 and A.3. The results in Figure A.2 correspond to an azimuth angle of 240° which is in the direction of the maximum positive (though relatively gentle) ground slope. Data shown in Figure A.3 were calculated for an azimuth angle of 315° which is the direction of the closest hill of high elevation. Calculated power densities for 10° or greater of beam
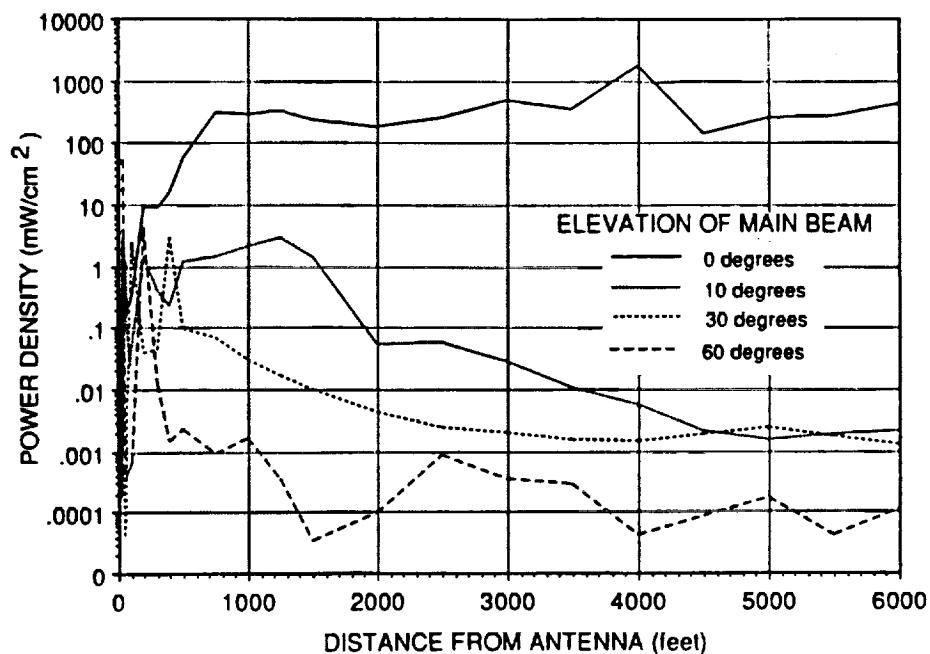
**FIGURE A.2.** Power Density Directly Under Main Beam of 70-m-diameter Antenna at 6 ft Above Ground (1 MW input power, azimuth = 240 degrees)
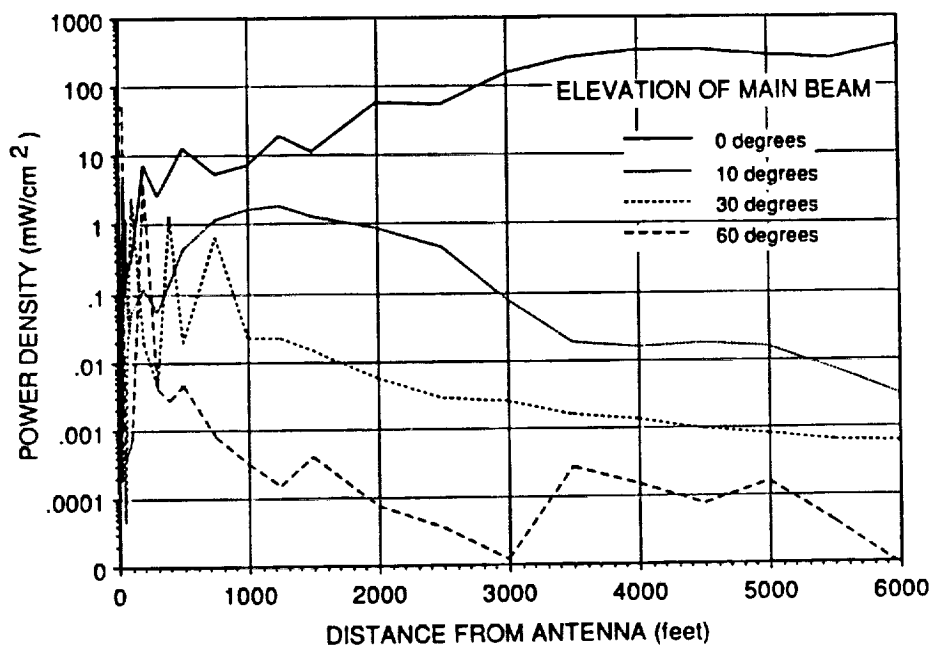


**FIGURE A.3.** Power Density Directly Under Main Beam of 70-m-diameter Antenna at 6 ft Above Ground (1 MW input power, azimuth = 315 degrees)

elevation are well within the ANSI Standard. Calculations made at and near the center of the main beam are given in Figures A.4 and A.5. The values of calculated power densities surrounding and within the collimated beam are of the same diameter as the antenna dish and are well above the ANSI/IEEE Standard. Note that the levels of radiation are greater than 100 mW/cm$^2$ out to distances corresponding to the diameter of the antenna dish. Though these values appear to greatly exceed the draft 1991 ANSI/IEEE guidelines for the uncontrolled environment (approximately 5.7 mW/cm$^2$ averaged over any 10.6 minute period), it is very unlikely that any moving aircraft would be in the beam for a long enough period to exceed this limit. For example, exposure to the 100 mW/cm$^2$ level would have to occur for a period greater than 36.2 seconds for the draft 1991 ANSI/IEEE Guidelines to be violated. There would be a problem, however, if hovering aircraft such as helicopters entered and stayed in the main beam of the antenna. It is unlikely that birds or other airborne biota would remain in the main beam except for brief exposures. Within 100 m of the antenna, power density may exceed the ANSI/IEEE Standard. Personnel should not approach within 100 m of the antenna without surveying the RF field to ensure power density is below acceptable limits.


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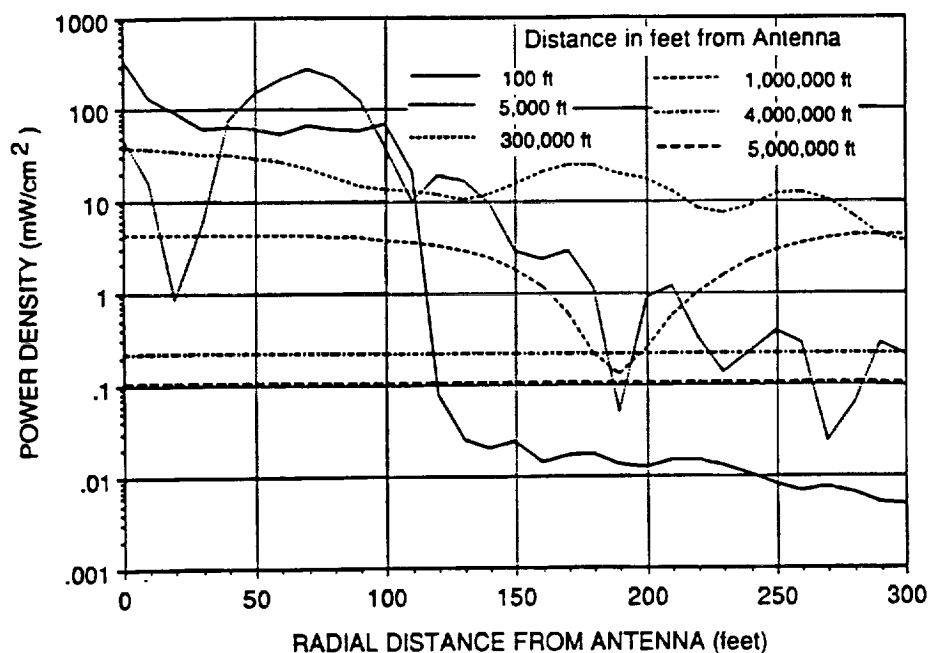
**FIGURE A.4.** Power Density Across Main Beam of 70-m-diameter Antenna
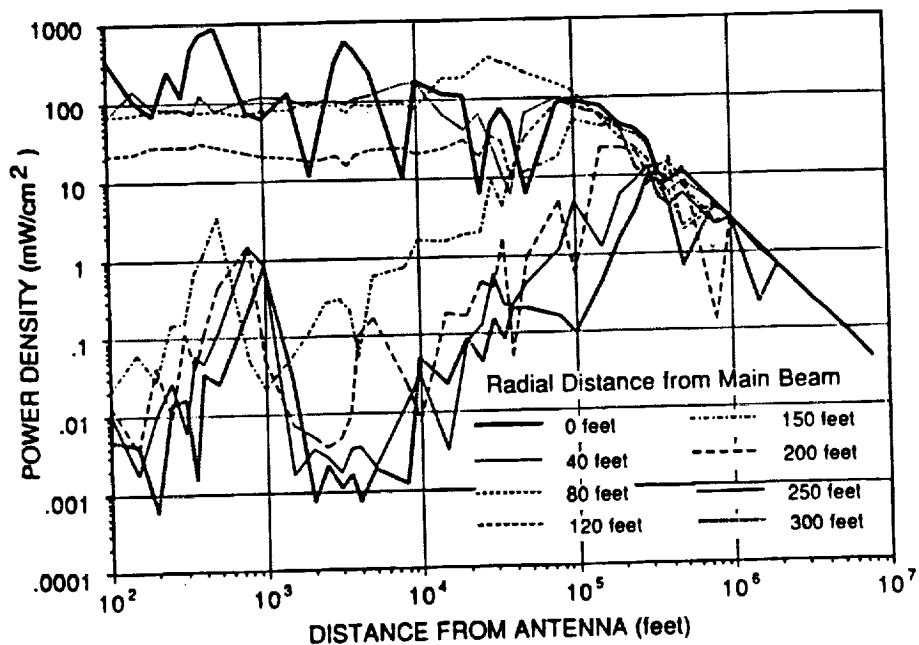


**FIGURE A.5.** Power Density Along Main Beam of 70-m-diameter Antenna

A-8

APPENDIX B


DESCRIPTION OF THE THEORETICAL STUDY OF THE MICROWAVE RADIATION LEVELS
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## B.1 RADIATION CHARACTERISTICS OF MICROWAVE DISH ANTENNAS

The microwave reflector antennas considered in this study have very narrow beams and are very large compared to a wavelength. There are three important regions for classification of the fields near large aperture parabolic reflector antennas of the type considered in this study: 1) the Fresnel or near zone, 2) the transition zone and, 3) the Fraunhofer region or far zone. In the near field the energy emitted by the antenna can be considered as being confined mostly within a cylindrical region having the same diameter, D, as the antenna. This region may be considered to extend out to a distance, d, from the antenna of

$$d = D^2 \pi / (8\lambda) = AR/(2\lambda) \tag{1}$$

where AR is the area of the antenna aperture and $\lambda$ is the wavelength. The power density in the Fresnel region is very nonuniform reaching a maximum of 4 times the average value in the cylindrical region at a distance of

$$d = 0.2D^2/\lambda \tag{2}$$

from the antenna. However, in considering radiation hazards it is usual to assume that the worst case near zone power density

$$W_n = 4P/AR \tag{3}$$

occurs throughout the full length of the cylindrical region where P and AR are the antenna input power and area respectively. The power density decreases rapidly with radial distance from the cylindrical region, becoming 10 db less than that at the axis at a distance of $0.6D^2/\lambda$ from the axis.

In the far field region, beginning at a great distance from the antenna, the radiation pattern of the antenna has been formed and the power density decreases as the inverse square of distance from the antenna. It can be shown that this distance is

$$d = 2D^2/\lambda. \tag{4}$$

In this region the free space power density of the antenna is given by

$$W_f = F(\Theta,\phi)G/(4\pi r^2) \tag{5}$$

where G is antenna gain, $F(\Theta,\phi)$ is the antenna power pattern, $\Theta$ is angle between the beam axis and a line to point of calculated power density, $\phi$ is the angle between a plane formed by a horizontal line across the center of the antenna aperture and a line perpendicular to the antenna aperture, and the plane formed by the antenna main beam and the line from the center of the antenna aperture to the point of calculated power density, and r is the distance from the antenna. The transition zone corresponds to the region between the near zone and the far zone corresponding to a distance about 5 times the length of the near zone region. Since the power density on the axis of the antenna decreases approximately as the square of distance from the near zone field region in this zone, a conservative approach is to use the far zone formula to calculate power density as a function of distance from the antenna at locations beyond where the far zone and near zone expressions give the same value of power density on the antenna axis. Along the axis of the antenna $F(\Theta,\phi) = 1$. This requires

$$GP/(4\pi r^2) = 4P/AR$$

or (6)

$$r^2 = AR(G)/16\pi$$

giving

$$r = [AR(g)/16\pi]^{1/2} \tag{7}$$

The power density in the far zone will vary according to the antenna power pattern $F(\Theta,\phi)$ as a function of angles $\Theta$ and $\phi$ with respect to the antenna beam axis. The angle $\Theta$ for the microwave antenna may be determined

from the antenna elevation angle E and azimuth angle ψ of the beam with respect to the point of observation based on the geometry in Figure B.1.
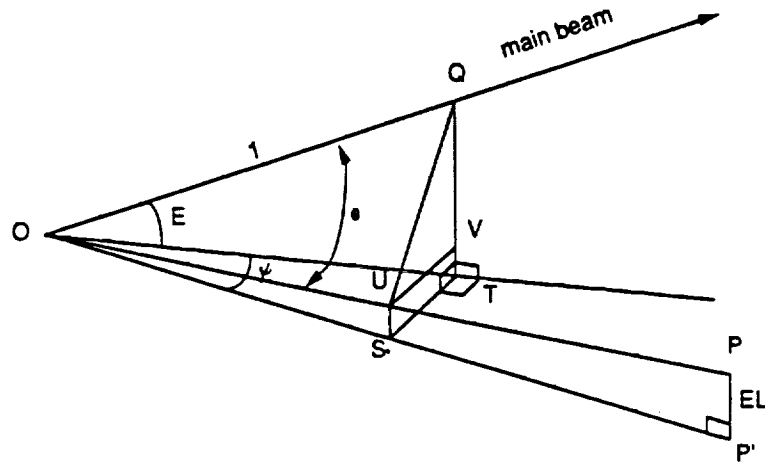


<u>FIGURE B.1</u>.  Geometry Associated with Calculation of Antenna Radiation Power Density at Point P at an Elevation EL Above an Antenna Located at O

   Point O corresponds to the position of the antenna and point P is the location where the power density is desired.  This point is at an elevation of EL and a horizontal distance OP′ from the antenna position.  If we consider a point Q on the antenna beam at unity distance from the source, the horizontal projection of OQ is OT.  The following relations are true.

$$OTQ = STQ = OTS = 90°$$  (8)

$$QT = \sin E$$  (9)

$$OT = \cos E$$  (10)

$$OS = \cos E / \cos(\Psi)$$  (11)

$$UV = ST = \tan(\Psi)\cos E$$  (12)

$$VT = US = (EL \cos E)/[(OP'\cos(\Psi)]] \tag{13}$$

$$UQ = [(\sin E - \frac{(EL)\cos E}{(OP')\cos(\Psi)})^2 + \tan^2(\Psi)\cos^2 E]^{1/2} \tag{14}$$

$$OU = \left[\left(\frac{EL\cos E}{OP'\cos(\Psi)}\right)^2 + \frac{\cos^2 E}{\cos^2\Psi}\right]^{1/2} \tag{15}$$

$$\cos \Theta = \frac{(OU)^2 + 1 - (UQ)^2}{2(OU)} \tag{16}$$

therefore

$$\Theta = \cos^{-1}\left[\frac{(OU)^2 + 1 - (UQ)^2}{2(OU)}\right] \tag{17}$$

and

$$r = OP = [(OP')^2 + (EL)^2]^{1/2} \tag{18}$$

The angle $\phi$ may be obtained as a function of the antenna beam elevation angle E and azimuth angle to the point of measurement based on the geometry in Figure B.2 and the expression:

$$\phi = \tan^{-1}[(B \sin(E - \xi))/\sin\Psi] \tag{19}$$

where    $B = (\cos^2\psi + \tan^2\delta)^{1/2}$,

$\xi = \tan^{-1}(\tan/\cos\psi)$

and    $\tan\delta = EL/OP'$

**FIGURE B.2.** Geometry Associated with Calculation of Antenna Pattern Angle, $\phi$, as Function of Azimuth Angle, $\psi$, Elevation Angle, E, Elevation of Observation Point, EL, and Distance from Antenna, r

## B.2 REFLECTIONS FROM THE GROUND

The above expressions apply to free space power density. With the presence of the ground or reflecting objects which are usually in the vicinity of exposed persons, there can be reflections causing both destructive and constructive interference. Since the reflected waves may add in phase with the primary wave at some locations, the power density could reach a maximum of 4 times that of the incident wave. Thus for purposes of safety evaluation it is prudent to multiply the values calculated from the above equations by a factor of 4.

## B.3 CALCULATION OF NEAR FIELD POWER DENSITY

Equation 5 applies only for the far zone field corresponding to a distance greater than $2D^2/\lambda$. This distance is 288 kilometers for the 70 meter JPL antenna. However, the NEC reflector antenna computer code will allow the equation to be used by calculating an equivalent value for the product of the pattern $F(\Theta,\phi)$ and gain G for any distance greater than 1 antenna reflector diameter or greater distance. However, this near zone gain function $Fn(\Theta,\phi,r)$ = $Fn(\Theta,\phi)G$ is also a function of distance r from the antenna as well as the two angles. The equation for near zone power density including worst case ground reflections becomes

$$W_f = F_n(\Theta,\phi,r)/\pi r^2 \qquad (20)$$

APPENDIX C

ASSESSMENT OF SCIENTIFIC INFORMATION CONSULTED IN
THE PROPOSED UPGRADE TO 1 MEGAWATT OF THE
DSS-14 TRANSMITTER AT THE 70-METER MARS ANTENNA AT THE GDSCC

(The text and illustrations in this Appendix
were provided to JPL
by Battelle Pacific Northwest Laboratories.
Richland, Washington)

ASSESSMENT OF SCIENTIFIC INFORMATION CONSULTED IN THE PROPOSED
UPGRADE TO 1 MEGAWATT OF THE DSS-14 TRANSMITTER AT THE
70-METER MARS ANTENNA AT THE GDSCC

## C.1 INTRODUCTION

The information contained in this section is summarized from Heynick
(1987). In an assessment of the potential biological effects of RFR from a
specific system, it is necessary to consider certain quantitative relation-
ships among (1) the physical parameters of the RFR such as frequency, power
density, and polarization; (2) the mechanisms of absorption and distribution
of energy within the biological organism; and (3) the resulting biological
effects as measured by some functional or anatomic alteration. Like all
scientific theory, the body of biophysical theory that links these three
factors has been synthesized from a variety of experimental evidence. The
theory is subject to refinement or revision as valid new evidence accumulates
that is inconsistent with the theory. Nevertheless, it furnishes the context
in which new experimental evidence is considered.

The most directly applicable experimental evidence concerning possible
bioeffects of any specific system would come from experiments in which humans
were exposed to its specific frequency range and likely power density values.
Furthermore, the best evidence would come from quantitative evaluation of a
large number of biological endpoints. Such data, however, do not exist. The
relatively small amount of data on human exposure to RFR were derived primarily
from epidemiologic studies conducted after exposure. Such studies are rarely
adequate because the numerical values of the exposure parameters for most
epidemiologic studies are not known in detail, and the unexposed control group
of people selected for comparison may differ significantly from the exposed
population in factors other than exposure to RFR. Most available information
is indirect because it is derived primarily from experiments with animals and
requires at least some extrapolation of species, field characteristics,
duration of exposure, and biological effects.

Regardless of the particular line of evidence being considered, certain
concepts and constraints affect the interpretation. In particular, scientists

disagree over whether an effect, especially one that is reversible or compensable, constitutes a hazard. Furthermore, only rarely is any particular study subjected to confirmation by the performance of an identical experiment by another investigator. More often, an analogous--but not identical--experiment is conducted with the objective of clarifying or expanding the results of the initial experiment. The second experiment ideally provides a better means of incorporating the findings into the theory that underlies the body of knowledge in a particular field of investigation, but it does not necessarily confirm the results of the first investigation.

Still another consideration is also important: scientific findings are probabilistic in nature, in that facts are known only to some level of probability for a given population; the applicability of those facts to a particular individual may be constrained. For example, the term "median effective dose" for a certain agent refers to the dose that will elicit the response characteristic of that agent in one-half of the exposed individuals. Before the dose is administered, however, one cannot predict whether any specific individual will respond, although the prediction that an individual will have a 50% chance of showing the response is valid. In effect, the probabilistic nature of scientific evidence means that no amount of scientific data can guarantee the absolute safety of any agent for any individual or group of individuals. Analysts disagree over whether the conventional scientific approach, whereby an investigator finds or fails to find a statistically significant (very low probability of chance occurrence) difference between experimental and control groups, is appropriate to considering potential hazards to humans. The scientist's statement that no statistically significant differences between the groups are discernible is not equivalent to the absolute statement that there is no difference between the groups.

Conceivably, agents may have effects that are biologically real but so small in magnitude that the difference in mean response between experimental and control populations may not be discernible within the scattering of values for both populations if the sample sizes are small. Biological studies to detect such small differences and to show that they are statistically significant (to a prespecified probability that they are not due to chance)

would require the use of large numbers of animals and, in some cases, long exposure times. The expenditures in time and money necessary to perform such studies may be so large that sponsoring institutions with limited budgets often decide that such studies are not cost-effective in terms of the sponsor's overall objectives. A frequent alternative is to predict effects at very low levels by extrapolation from findings at higher levels, on the basis of assumptions about the mathematical relationship between the level (or dose) of the agent and the degree of the effect. Such assumptions are open to challenge, however, and this approach may lead to disagreement over the possible existence of a threshold dose or dose rate below which the agent has no effects.

It must also be remembered that scientists have personal values, goals, and attitudes. It has been said that there is no such thing as an unbiased expert because becoming an accepted authority involves a personal commitment over a period of time that leads to emphasis of certain viewpoints. Thus, like probabilistic scientific findings, objectivity may well be characteristic of scientists as a group without necessarily being characteristic of any individual scientist. Personal bias can consciously or unconsciously affect how the experiment is designed, how the data are interpreted, and particularly, how the results are applied to decision making. The last is especially important when the decision to be made is in an area outside the scientist's field of expertise.

Finally, scientific experiments are usually restricted to the evaluation of only one factor. In the real world, however, interactions are far more complex. The effect of combinations of factors is illustrated in the incidence of lung cancer in uranium miners, which is higher than in the general population, presumably as a result of the inhalation of radioactive material. The extent of the increased incidence in nonsmoking miners is marginal, but miners who smoke cigarettes have a much higher incidence of lung cancer than either nonsmoking miners or the general population. Thus, scientific evidence can only supply probabilistic information that is relatively narrow in its application to the real world.

## C.2 PRESENT STATE OF KNOWLEDGE REGARDING PHYSICAL EFFECTS

### C.2.1 Interactions of RFR with Biological Systems

Interactions of electromagnetic fields with biological systems are often loosely characterized in the bioeffects literature as "thermal" or "non-thermal," a usage that has led to confusion and controversy. Therefore, it is appropriate at this point to introduce working definitions of these terms, with the recognition that the boundary between these types of interaction is not sharp.

The interaction of an agent (e.g., RFR) with an entity (biological or nonbiological) can be characterized as thermal if the energy absorbed by the entity is transformed at the absorption site into heat. Heat absorption, in turn, is defined in classical thermodynamics as either an increase in the mean random speed (or kinetic energy) of the molecules at the site (a local increase in temperature), or as an increase in the disorder or randomness of the molecular motion without an increase in mean random speed (a first-order phase change, such as the process involved in ice melting at 0°C), or both.

A system can also absorb energy at specific discrete frequencies in the form of energy packets or quanta, each of which has an energy proportional to one of the discrete frequencies. Although large numbers of molecules can be involved, quantum absorption is essentially a microscopic phenomenon in that the constituents and configurations of the various molecular species comprising the entity determine the specific frequencies or characteristic spectra at which such absorption can occur. The kinds of interactions involved are numerous and of varying degrees of complexity. They include alterations of molecular orientations and configurations that do not change the basic identities of the molecules, disruption of intermolecular or intramolecular bonds, and excitation of atoms or molecules to higher electron states (including ionization). Such interactions can be characterized as "short-range" processes.

It is theorized that cooperative interactions also occur among subunits of molecules within biological cells, in cell membranes, and in extracellular fluids. Cooperative interactions are often characterized as "long-range" because absorption of energy at one specific site in a structure (e.g., in a

membrane or in a biological macromolecule) can affect a process elsewhere in the structure, or a function of the structure as a whole can be triggered by the release of energy stored in the structure, thereby producing biological amplification.

Conceptually, all such quantum interactions can be characterized as "nonthermal." However, if most of the energy thus absorbed is subsequently transformed locally into heat (as defined above), the distinction between nonthermal and thermal is blurred. Pragmatically, therefore, characterization of an interaction of RFR with a biological entity as nonthermal requires that the interaction give rise to a frequency specific effect that is experimentally distinguishable from heating effects caused by thermalization of the absorbed RFR energy.

## C.2.2 Thermal Interactions

Consider now the effects of continuous wave (CW) RFR on a human or an animal. The relative magnetic permeability of most organic constituents is about unity. Therefore, thermal interactions (as defined above) can be described in terms of the dielectric, electrically conductive, and thermal properties of the body organs, tissues, fluids, and so forth, as well as the characteristics of the RFR (frequency, power density, polarization). Measurements of these properties have been made for various mammalian tissues, blood, cellular suspensions, protein molecules, and bacteria over the frequency range from about 10 Hz to 20 GHz. In the subrange from about 300 MHz to about 10 GHz, the dielectric constant of such constituents as skin, muscle, and blood vary little with frequency; the differences in values among such constituents are largely due to differences in water content. In addition, electrical conductivity increases slowly with frequency in this subrange.

Because the index of refraction of any material is related to its dielectric constant, RFR is reflected and refracted at boundaries between regions of differing dielectric properties, such as at the surface of a body (whether organic or inorganic), for the same physical reasons as for light at a glass-air interface. Thus, RFR at normal incidence to a relatively thick planar specimen is partially reflected at the surface, and the fraction of the

power density entering the specimen suffers progressive attenuation with depth because of energy absorption. The concept of "penetration depth" is often used. For homogeneous specimens, the penetration depth is defined as the distance at which the electric-field strength is about 37% of its value or the power density is about 14% of its value just within the surface, and the numerical values depend on the electrical properties of the material. Both the reflection ratio and penetration depth vary inversely with frequency. At 450 MHz, about 65% of the incident power density is reflected at the air-skin interface, and the penetration depths for skin, muscle, and blood are about 3 cm (1.2 in.) and about sixfold larger for fat. Therefore, the 35% entering the body passes through the skin and its underlying fat layer into the muscular tissue with relatively little attenuation. At 100 kHz, the penetration depths of all constituents are quite large, but the reflection ratio is essentially unity. On the other hand, at the approximate frequency of the research system (RS), a somewhat smaller fraction of the incident power density than at 450 MHz is reflected, but penetration is largely confined to the skin.

## C.2.3 Dose-Rate Considerations

In the literature on bioeffects of RFR, thermal energy absorption from an electromagnetic field is usually characterized by the specific absorption rate (SAR), which is defined as the rate of energy absorption per unit volume in a small volume at any locale within an entity, divided by the mean density of the constituents in that volume. SAR is expressed in terms of W/kg or mW/g (1 mW/g = 1 W/kg). The numerical value of SAR in any small region within a biological entity depends on the characteristics of the incident field (power density, frequency, polarization), as well as on the properties of the entity and the location of the region. For biological entities that have complex shapes and internal distributions of constituents, spatial distributions of local SAR are difficult to determine by experiment or by calculation. Thus, the concept of "whole-body SAR," which represents the spatial average value for the body per unit of incident power density, is useful because it is a quantity that can be measured experimentally--e.g., by calorimetry--without information on the internal SAR distribution.

Many investigators have calculated or measured SAR for relatively simple geometric models, including homogeneous and multilayered spheroids,

ellipsoids, and cylinders that have weights and dimensions approximately representative of various species, including humans. An important result of this work is that the largest value of whole-body SAR is obtained when the longest dimension of each kind of model is parallel to the electric component of a linearly polarized plane-wave field and when the wavelength of the incident RFR is about 2.5 times the longest dimension. The adjective "resonant" is often applied to the frequency corresponding to this wavelength. The resonant value of whole body SAR for each model is also inversely dependent on the dimension perpendicular to the polarization direction (and propagation direction) of the field; i.e., the model has characteristics somewhat similar to those of a lossy dipole antenna in free space. Resonances would also occur for circularly polarized RFR. Such RFR can be resolved into two mutually perpendicular components, each having half the total power density. Therefore, an organism exposed to circularly polarized RFR would have lower resonant SAR values than it would have if exposed to linearly polarized RFR of the same total power density.

Based on prolate-spheroidal models (and linearly polarized RFR), the resonant frequency for an "average" man, approximately 5 ft 9 in. tall (1.75 m) and weighing about 154 lb (70 kg) is about 70 MHz; at this frequency the mean SAR is about 0.2 W/kg for 1 mW/cm$^2$ incident power density, or about 1/6 of his resting metabolic rate, or about 1/21 to 1/90 of his metabolic rate when performing exercise ranging from walking to sprinting. An alternative interpretation of this mean SAR value is that exposure to 1 mW/cm$^2$ for, say, 1 hr would produce a mean temperature rise of about 0.2°C in the absence of any heat-removal mechanisms. However, actual temperature increases would be lower or even zero because physical heat-exchange mechanisms (conduction, convection, radiation) are always present, and for mammals (and other warm-blooded species) these mechanisms are controlled by thermoregulatory systems.

Similarly, the resonant frequency for an "average" woman about 5 ft 3 in. tall is about 80 MHz, and her mean SAR is about the same as for the average man. The resonant frequency of a 10-year-old is about 95 MHz; for a 5-year-old, about 110 MHz; and for a 1-year-old, about 190 MHz. The mean resonant SAR values for such children are about 0.3 W/kg for 1 mW/cm$^2$.

If a model human were to be standing on a wet surface or near other electrically conductive surfaces (reflectors), the resonant frequency would be lower and the mean SAR (at the lower resonant frequency) would be higher. However, because the values of incident power density from the RS at ground level beyond the exclusion area are $\leq 1$ mW/cm$^2$ and its operational frequencies are considerably higher than the resonant frequencies in either the absence or presence of nearby reflecting surfaces, no changes in body temperature would be expected.

The foregoing discussion of mean SAR also largely applies to pulsed RFR (and other types of modulated RFR) at corresponding carrier frequencies and time-averaged incident power densities. However, as discussed in the next section, interactions of CW and pulsed RFR with biological entities differ in several ways.

An early, very significant finding for spherical models of the isolated head assumed to be exposed to plane-wave RFR was the discovery of local regions of relative maximum SAR values. The locations of such regions depend on the size of the head, the electromagnetic characteristics of its layers, and the wavelength of the incident field. These regions have been conveniently dubbed "hot spots," even for combinations of incident power density and exposure duration that would produce biologically insignificant temperature increases at such spots. Pertinent hot-spot data are given in the RFR-bioeffects review.

Results of theoretical analyses of SARs have been verified experiment- ally. Physical models of simple geometry of human or animal shapes were constructed from synthetic biological materials that have approximately the same electromagnetic characteristics as their corresponding biological constituents; the models were then exposed to sufficient power densities to obtain readily measurable temperature increases, which were measured immediately after irradiation.

Among the qualitative results of general interest obtained with these human and animal phantoms are that, at frequencies near resonance, the local fields can be much higher for certain regions such as the neck and groin than for other body locations, and that field distributions for nonprimates differ

greatly from those for primates. The latter point should be given proper consideration when one endeavors to extrapolate experimental bioeffects findings on any laboratory animal species to humans or to compare experimental results on one laboratory species with those on another species. However, the RS frequency is much higher than the human resonance values (e.g., 70 MHz for the model average man) and the corresponding mean SAR values (per $mW/cm^2$) are considerably lower than the resonance values (e.g., about 0.01 W/kg at 7 GHz versus 0.2 W/kg at 70 MHz). Consequently, local temperature rises in body regions such as the neck and groin would be negligible for the power densities beyond the exclusion area.

## C.2.4 Quantum Interactions and Nonthermal Effects

It has been postulated that cooperative or long-range quantum processes in biological systems (or the functions resulting therefrom) could be altered by exposure of the system to external fields of magnitudes that do not produce heat as the primary or initial product. Much research has been done with models of cellular membranes. In general, the results indicate that cooperative processes have activation energies or exhibit resonant frequencies that can be much lower than those for short-range interactions.

The mean thermal energy corresponding to the physiological temperature 98.6°F (37°C) is about 0.027 eV, with a classical spectral distribution around a maximum at 6.5 GHz and encompassing the frequency range for cooperative processes. Therefore, as a counter argument to the manifestation of such nonthermal effects, a question has been raised whether these effects would be distinguishable from those that are spontaneously induced thermally in vivo. Alternatively, separation of such RFR interactions from those thermally induced may require that the rates of occurrence of the former exceed the rates for the latter. This requirement implies that for manifestation of such effects of RFR, the intensity of the incident field must exceed minimum values or thresholds related to the specific processes.

Because predictions from various theoretical models and related considerations conflict to a significant extent, the issue of whether weak external fields at frequencies well below the infrared range (i.e., RFR) can alter biological processes is not yet resolved. However, increases and

decreases of calcium-ion binding to cell membranes due to weak external RFR, a phenomenon called "calcium efflux," have been ascribed to alterations of cooperative processes by such fields.

## C.2.5 Interactions of Modulated RFR

Precise usage of the term CW RFR implies the presence of only a single frequency (and unvarying incident power density). Because of the time variations of power density and/or frequency in modulated RFR, possible biological effects ascribable to the modulation characteristics per se rather than to the time-averaged power density must also be considered, such as the calcium-efflux phenomenon, which was reported for 50 MHz, 147 MHz, and 450 MHz RFR modulated at sub-ELF frequencies but not for unmodulated RFR at these carrier frequencies.

Periodically pulsed RFR constitutes a particular type of amplitude-modulated RFR in which the pulse repetition rates are the primary modulation frequencies. Biological effects ascribable to modulation frequencies per se (as distinguished from those due to individual pulses) have been postulated. The calcium-efflux results are not relevant to the RS because the pulse repetition rate of the RS is not similar to the modulation frequencies used in those experiments.

## C.2.6 Interactions of RFR Pulses

The interactions of individual RFR pulses with a system (biological or nonbiological) are analogous to those of mechanical impulses, an impulse being defined as the sudden application of a force to an entity for a brief time interval, resulting in an abrupt increase in momentum. The total energy imparted to the entity depends on the magnitude of the force and the duration of its application. The interaction can be characterized as nonthermal or thermal, depending on the properties of the entity that determine the disposition of the energy. The impact of a piano hammer on a string, which excites the string into vibration at its discrete resonant frequencies (the fundamental frequency and integer-multiples thereof or harmonics), is an example of an essentially nonthermal interaction as defined previously; most of the energy is transformed into sound, which is converted into heat elsewhere.

A sudden blow to a system such as a block of material having a set of resonant frequencies that are not necessarily harmonically related to one another will excite many of these frequencies; this illustrates the principle that an impulse contains a broad spectrum of frequencies. The results of an impact on a church bell can be characterized as nonthermal for the same reason as that given for the piano string. By contrast, the effects of a blow to a block of lead or asphalt are essentially thermal; even though some sound is produced, most of the energy is converted into heat on the surface of impact.

The temperature increase of any given region within a biological system due to the arrival of a single RFR pulse would be small, because of the relatively large thermal time constants of biological materials and the operation of heat-exchange mechanisms. However, if the region contains a boundary between layers of widely different dielectric properties, then the temperature gradient (rate of temperature change with distance) can be large at such a boundary even though the mean temperature increase in the region is small.

One single-pulse effect known to occur in humans is the phenomenon of "microwave hearing", or the perception of single or repetitive short pulses of RFR as apparently audible clicks. The interaction mechanisms involved are not yet completely understood. However, most of the experimental results tend to support the theory that pulse perception occurs because the electromagnetic energy is transduced into sound pressure waves in the head at a boundary between layers having widely different dielectric properties (e.g., at the boundary between the skull and the skin or the cerebrospinal fluid). The energy in a pulse arriving at such a boundary is converted into an abrupt increase in momentum that is locally thermalized, producing a negligible volumetric temperature increase but a large temperature gradient across the boundary. Under such conditions, rapid local differential expansion would occur and create a pressure (sound) wave that is detected by the auditory apparatus. This effect is often characterized as nonthermal because the power density averaged over two or more pulses can be minuscule. Specifically, the time-averaged power density for two successive pulses is inversely proportional to the time interval between the arrival of the pulses at the perceiver, and this interval can be indefinitely long without affecting the

perception of each pulse. Therefore, the time-averaged power density has no relevance to perception. Irrespective of how the RFR-hearing phenomenon is characterized, the significant point is that the preponderance of experimental evidence indicates that the pulses are converted into actual sound in the head, rather than perceived by direct RFR stimulation of the auditory nerves or the brain.

Pulsed RFR has been reported to produce other effects, such as alterations of the blood-brain barrier and behavioral changes.

### C:2.7 Exposure Systems and Instrumentation for RFR Bioeffects Research

Much of the early laboratory research on RFR bioeffects suffered from lack of adequate systems for exposing the biological organisms under study and lack of accurate techniques and instrumentation for measuring incident fields and/or determining energy absorption rates within such organisms. The environmental characteristics of the exposure systems were often inadequately characterized or controlled. In addition, the instrumentation was frequently incorrectly used, or was the source of significant errors in numerical values or of spurious biological findings (artifacts) traceable to perturbations introduced by the presence of the sensors. For these reasons, many of the early results should be viewed as questionable, at least from a quantitative standpoint. During recent years, however, major advances have been made in specialized exposure systems and in instrumentation for determining incident-field intensities for biological research and for determining energy-absorption rates within biological entities.

### C.3 PRESENT STATE OF KNOWLEDGE REGARDING BIOLOGICAL EFFECTS

### C.3.1 Epidemiology

Epidemiology, as used in the context of this document, refers to studies of whether one or more health-related conditions can be associated statistically with purported or actual exposure of humans to RFR (in contrast with assessments based on extrapolation from data on animals to humans). Epidemiologic results tend to be based on imprecise estimates of exposure characteristics (frequency, power density, and duration). The extent to which the control group matches the exposed group is sometimes open to question.

Because matching of all relevant factors except exposure is the basis for concluding that any observed differences between groups are related to the RFR exposure, selection of an appropriate control group is critical. Despite these limitations, such studies do provide almost the only information available on possible effects of actual RFR exposure in humans.

A group of reports was selected for review from the literature in the United States, Poland, Czechoslovakia, and the USSR. These reports provide a representative sample of the kinds of information currently available.

The U.S. Embassy in Moscow was subjected to RFR from 1953, the year after the United States moved its chancery to Chekovsky Street, until February 1977. Within rooms having the highest RFR levels (rooms with windows or doors in outside walls toward the irradiation sources), the average power densities were typically about 0.004 mW/cm$^2$ within 2 ft of a door or window, and 0.00025 mW/cm$^2$, elsewhere in the room. The highest power density reported was 0.024 mW/cm$^2$ which occurred in one room during a 2-hr period of unusual signal strength on 24 January 1976.

A study was made of the health of U.S. personnel assigned to the Moscow embassy during the period from 1953 to 1976, compared with the health of those assigned to other U.S. Eastern European embassies. The investigators noted several limitations of the study but were able to conclude that there were no discernible differences between the Moscow and control groups in total mortality or mortality from specific causes, nor were there differences in mortality between the Moscow and control groups of dependent children or adults.

In a study published in 1965 of the causes of Down's syndrome in U.S. children, an apparent correlation was found between this inherited condition and exposure of the fathers of affected children to RFR before their conception. However, in a later study (1977) in which the original study of 216 children was expanded to 344 children with Down's syndrome, each matched with a normal child of the same sex born at about the same time and whose mother was about the same age, no such correlation was found. Thus, the earlier conclusion, based on a smaller sample, that exposure to RFR

contributed to Mongolism in offspring, was not confirmed.  No quantitative assessment of the extent of the fathers' exposures was possible.

The causes of mortality in personnel who had served in the U.S. Navy during the Korean War were monitored in an attempt to establish whether exposure to RFR is associated with causes of death or with life expectancies. By 1977, the records of about 20,000 deceased veterans whose military occupational titles indicated more probable exposure to RFR had been compared with the records of an approximately equal number of less-exposed veterans. No quantitative exposure data were available. No differences between groups emerged in overall mortality rates or in the rates for about 20 specific categories of cause of death.  However, death rates differed significantly for two categories:  death rates from arteriosclerotic heart disease were lower and those from trauma were higher in the RFR-exposed group.  The trauma category included military aircraft accidents, and a higher proportion of the exposed group had become fliers.  It therefore appeared unreasonable to attribute the higher trauma death rate to greater previous RFR exposure. Overall death rates for both groups were lower than those for the general U.S. population of the same age.

The incidences of fetal anomalies and fetal death rates reported in birth records for white children born in the vicinity of the Army Aviation Center at Fort Rucker, Alabama, between 1969 and 1972 were evaluated in a series of three reports.  Fort Rucker is of interest because of the concentration of radar units on or near the base.  Taken together, these reports identify unusually high incidences of certain fetal anomalies and high fetal death rates in the two counties adjacent to Fort Rucker as compared with the corresponding statewide Alabama statistics, and at the Lyster General Hospital (Fort Rucker) as compared with other military and civilian hospitals. A high incidence of fetal death at the Eglin AFB Hospital is also reported, but no further mention is made of the Eglin data in the remainder of the report.  However, there was also evidence that these high rates for Fort Rucker could not be attributed specifically to the unquantified radar exposures at or near Fort Rucker on the basis of the birth record data: Coffee and Dale counties ranked only sixth and eighth for anomaly incidence among the 67 Alabama counties; Lyster Hospital's anomaly and fetal death rates

were not significantly higher than several other comparable "non-radar" hospitals in Alabama and were in the range of values predicted from carefully controlled studies done in other states. The residences of mothers bearing anomalous infants were not clustered near radar sites, but many of the anomalies reported at Lyster occurred over a small time period, indicating a high anomaly-reporting rate for one or two physicians on the Lyster staff.

In 1971, a report was published on the results of a battery of medical evaluations carried out on 58 employees of Czechoslovakian television transmitter stations. Exposure frequencies were estimated to range from 48.5 to 230 MHz at field intensities equivalent to 0 to 0.022 mW/cm$^2$ with a mean exposure duration of 7.2 years (10.6 hr/workday). Electrocardiograms, heart and lung X-rays, standard blood tests, urinalyses, and liver function tests were conducted, as well as ophthalmologic, neurologic, gynecologic, psychiatric, and psychological examinations. The only statistically significant finding was that the mean plasma protein levels were higher than "normal" values taken from the literature, a finding that the author describes as unexplainable. The appropriateness of the use of literature control values is highly questionable.

In a later study (1974) by the same investigators, the effects of RFR on blood protein levels were reexamined. The authors indicated that the only difference between exposed and control groups was that the members of the exposed groups had worked irregular shifts, whereas more than half of the control group had worked only morning shifts. The results for both groups showed that the individual levels of blood proteins and their fractions were within normal physiologic limits, but statistically significant differences were found between mean values for the exposed and control groups.

The absence in either study of a control group that had received virtually no RFR exposure renders questionable an interpretation that any differences found were due to RFR exposure. It is likely that the altered values of blood proteins (which were within normal limits) were caused by other factors.

A 1974 report by another investigator in Czechoslovakia was an assessment of workers exposed to RFR at 1-150 MHz, 300-800 MHz, or 3-30 GHz,

with power densities, where specified, of 0.1 to 3.3 mW/cm$^2$, depending on their particular occupations. Changes were reported in brain wave patterns and in blood sugar, proteins, and cholesterol levels, as compared with those in administrative (nonexposed) personnel. The 3-30 GHz range includes the RS frequency, but no estimates of power density were given in the report.

The authors of a 1974 paper from Poland compared the health status and fitness for work of 507 persons occupationally exposed to pulsed RFR exceeding 0.2 mW/cm$^2$ average power density (other RFR characteristics not specified) with a group of 334 workers at the same installations exposed to less than 0.2 mW/cm$^2$. Clinical tests included ophthalmoscopic and neurologic examinations, supplemented by psychological tests and electroencephalograms (EEGs). No statistically significant differences between the two groups were found. This suggests that the lack of more definitive RFR exposure data vitiates, but does not invalidate, the negative findings of this study; i.e., the results provide no evidence for RFR-induced effects on the health status of either group.

In a USSR paper published in 1974, the authors reported that their clinical examinations of a group of specialists working with RFR generators in the 40 to 200 MHz range for 1 to 9 years showed occurrences of functional changes in the central nervous system, described as vegetative dysfunction accompanied by neurasthenic symptoms. No organic lesions were found, but among the many specific changes reported were deviations in the physicochemical and functional properties of erythrocytes and leukocytes (red and white blood cells). The authors also conducted experiments with human volunteers and reported functional changes in the thermoregulatory and hemodynamic systems and in the thermal, optical, and auditory "analyzers." However, no RFR intensity values were given for either the specialists or the volunteers; most of the findings were presented in narrative form, with no actual data; and the nature of the control group studied was not described. Consequently, this paper provides little basis for affirming or denying the occurrence of possible adverse effects of occupational exposure in RFR.

Another Soviet investigator presented clinical observations on the health status of two groups of USSR RFR workers. Those in the first group (1,000) were exposed to up to a few mW/cm$^2$, whereas those in the second (180)

were exposed to values rarely exceeding several hundredths of a $mW/cm^2$, both at unspecified "microwave" frequencies. A group of 200 people of comparable backgrounds but presumably not exposed to RFR served as controls. Sixteen kinds of symptoms were reported, including fatigue, irritability, sleepiness, partial loss of memory, lower heartbeat rates, hypertension, hypotension, cardiac pain, and systolic murmur. In the higher-power-density group, the indices for 5 of the 16 symptoms were higher than those in the lower-power-density group; they were lower for 9 symptoms and about the same for the remaining 2. Incidents in the control group were lower than those in either exposed group for 15 of the 16 symptoms.

Several epidemiologic studies have been performed in the United States to ascertain whether chronic exposure to RFR could cause cataracts. As reported in 1961, eye defects were sought in a group of 475 persons who were believed to have been exposed to RFR at 11 military and nonmilitary establishments; a group of 359 persons served as controls. The investigators found a slight but statistically significant difference in defect scores between the two groups, but they expressed some doubt regarding the full validity of the scoring method used.

A 1965 report by several of the same investigators discusses the examination of Veterans Administration Hospital records of 2,946 Army and Air Force veterans of World War II and the Korean War who had been treated for cataracts. A control sample of 2,164 veterans was selected. On the basis of military occupational specialties, they classified each individual as a radar worker, a nonradar worker, or one whose specialty could not be discerned. In the radar group, they found 19 individuals with cataracts and 2,625 individuals without cataracts; in the nonradar group, 21 individuals had cataracts and 1,935 did not. (The remaining 510 subjects were in the unspecified occupational category.) These differences between the radar and nonradar groups are not statistically significant.

In 1966, these investigators reported on statistical analysis of the records of 736 microwave workers and 559 controls for minor lens changes, using a scoring range from 0 to 3. They reported that the defect scores increased with age for persons in both groups, but that the average score for the microwave group was significantly higher than for the control group. They

suggested that this finding is an indication that exposure to RFR may have an aging effect on the lens. However, no cataracts or decreases in visual acuity were found.

In a study published in 1973, which covered a period of 5 years, military personnel identified as having been occupationally exposed to RFR from radar and communications systems were matched as closely as possible in age and sex with other military personnel on the same bases who had not been occupationally exposed. Several ophthalmologists independently examined exposed and control personnel (without knowledge of the group to which each individual belonged). Opacities, vacuoles, and posterior subcapsular iridescence were taken as diagnotic precursors of cataracts. Each precursor was scored as either present or absent in each individual, and the binary data thus obtained were used for statistical analyses by age group and numbers of persons per age group. The results indicated that more people in older age groups exhibited these precursors, but the pooled data from several Army installations showed no statistically significant differences between exposed and control groups.

As in other epidemiologic studies, the accuracy and detail of the exposure histories (frequencies, intensities, durations, and so on) taken for either the exposed or the control groups in these three ocular studies are difficult to determine. However, the exposed groups quite likely did receive more RFR exposure than the control groups.

In summary, none of these U.S., Polish, and Czechoslovakian epidemiologic studies offers clear evidence of detrimental effects associated with exposure of the general population to RFR. However, the Soviet findings, which are consistent with the voluminous, early Soviet literature, suggest that occupational exposure to RFR at average power densities less than 1 mW/cm$^2$ does result in various symptoms, particularly those associated with disorders of the central nervous system (CNS). Because the USSR symptomatology has not been reported in Western studies and because of the marked differences between Soviet and Western publications in the procedures used for reporting data, any prediction of possible RFR hazards based on the USSR epidemiologic studies would require acceptance of these Soviet findings at face value. We conclude that, taking all of the epidemiologic studies

together, the results do not provide evidence that the RFR from the RS system will be hazardous to the population outside the exclusion fence.

## C.3.2 Mutagenesis and Cancer Induction

One frequently expressed concern about RFR is that it may cause mutations. Mutagenesis and cancer induction are considered to be related, and indeed many chemicals are screened for potential cancer-causing properties by using bacterial mutation tests. Several studies involving RFR for mutagenic effects have been carried out on bacteria, yeast, fruit flies (standard test systems for mutagenesis). All of these studies failed to demonstrate a mutagenic effect. No mutations attributable to RFR exposure were found.

Recently, there have been a number of studies which link cancer induction with exposure to electromagnetic fields. In most cases, studies have been done at power line frequencies (60 Hz). These studies are not directly applicable to exposure to RFR at 7 GHz. However, Milham (1985, 1988) has done epidemiological studies of individuals who operate amateur radio equipment and work in so-called "electrical" occupations. These individuals have had slightly higher risks for certain blood cancers. The studies are therefore only indicative of the possible weak carcinogenic properties of RFR.

In summary, all of the studies on mutagenic and cytogenetic effects of RFR exposure indicate that the effects found are probably related to heating. Ground level power densities outside the RS exclusion area are incapable of producing significant heating. There is no evidence that such low power densities are likely to cause mutagenic effects. In addition, the paper claiming that RFR exposure has increased the incidence of cancer does not provide compelling evidence that exposure to RFR is likely to cause cancer. Other studies have failed to find an effect of RFR exposure on the general health of the exposed animals or on the occurrence of cancer.

## C.3.3 Studies on Teratogenesis and Developmental Abnormalities

Teratogenesis in humans is the production of malformed infants by processes affecting their development in the womb. The term "developmental abnormalities" as used here refers to processes affecting the development of infants after birth. Teratogenic and developmental abnormalities occur naturally at a low rate in most animal species, and relatively little is known

about their cause. In a few cases, however, specific agents have been shown to cause significant teratogenic effects; hence, the possibility of teratogenic effects from RFR is an appropriate matter of public concern.

Teratogenic studies with RFR have used a variety of animal models. One set of studies was performed on pupae of the darkling beetle, *Tenebrio molitor*. Several reports from different laboratories stated that relatively low levels of RFR would produce developmental abnormalities in the pupae. A follow-up study in one of the laboratories, however, reported that the number of developmental anomalies depended on such factors as the source of the larvae and the diet fed to them before they entered the pupal stage. This study also reported that production of developmental anomalies under worst conditions required exposure for 2 hr at a mean SAR of 54 W/kg (approximately equivalent to 192 mW/cm$^2$).

Japanese-quail eggs were exposed to 2.45 GHz CW RFR at 5 mW/cm$^2$ (SAR of about 4 W/kg) for 24 hr/day during the first 12 days of development. The investigators found no gross deformities in the quail when euthanized and examined 24-36 hr after hatching, and no significant differences in total body weight or the weights of the heart, liver, gizzard, adrenals, and pancreas between RFR and sham-exposed groups. Blood tests showed statistically significant higher hemoglobin (contained in red blood cells and important in oxygen transport) and lower monocyte (a form of white blood cell) counts in the RFR-exposed birds, but no differences in the other blood parameters. The differences in mean temperature from egg to egg in the RFR-exposed arrays were as much as 0.5°C, rendering it difficult to associate these positive findings with RFR. In another study by the same investigators, groups of eggs were similarly exposed and the birds were reared for 5 weeks after hatching. No significant differences in mortality or mean body weights at 4 and 5 weeks were found between RFR- and sham-exposed groups.

Teratogenic effects of RFR have been reported in several studies in mice and rats. In an early major study, pregnant mice were exposed on day 8 of pregnancy (gestation) to 2.45 GHz RFR at 123 mW/cm$^2$ for 2 to 5 min, corresponding to doses in the range 3-8 cal/g. On gestational day 18, the litters were examined for resorptions, and for dead, stunted, malformed, and apparently normal fetuses. No abnormalities were reported at doses less than

3 cal/g, which correspond to about 25 to 30% of the lethal dose for these animals. At doses above 3 cal/g, some abnormalities were obtained, notably exencephaly, a disorder in which the skull does not close and the brain is exposed ("brain hernia").

In another investigation, pregnant mice were exposed to 2.45 GHz RFR for 100 min daily on gestational days 1 through 17 at 3.4 to 14.0 $mW/cm^2$ or on gestational days 6 through 15 at 28 $mW/cm^2$. Control mice were sham-exposed similarly. All mice were euthanized on day 18 and their uteri were examined for the number of resorbed and dead conceptuses and live fetuses. The live fetuses were examined for gross structural alterations and weighed. Ten types of anomalies were tabulated by the numbers of litters affected. A total of 27 of the 318 RFR exposed litters, irrespective of power density, had one or more live abnormal fetuses, versus 12 of the 336 sham-exposed litters. For most of the individual anomalies, the numbers of litters affected were either too small for statistical treatment or no RFR-related pattern was apparent. The mean live fetal weights of the litters exposed at power densities of 14 $mW/cm^2$ lower were not significantly different from those of the corresponding sham-exposed litters. The latter finding was confirmed in a subsequent study by these investigators. In addition, some of the mice exposed at 28 $mW/cm^2$ were permitted to come to term, and the mean weight of their offspring at seven days of age was found to be about 10% less than that of control mice. However, there were no differences in survival rate between RFR-exposed and control offspring.

Other studies with pregnant mice at sublethal exposure levels yielded both comparable and conflicting results, presumably because of differences in experimental apparatus and procedures, but no evidence that doses less than 3 cal/g or power densities less than 1 $mW/cm^2$ are teratogenic.

Several similar studies were conducted with pregnant rats. In a representative recent study, 70 rats were exposed to 2.45 GHz CW RFR for 100 min daily on gestational days 6 through 15 at 28 $mW/cm^2$ (estimated SAR of 4.2 W/kg). The mean colonic temperature at the end of each exposure period was 104.5°F (40.3°C). A group of 67 rats was similarly sham-exposed. No significant differences between groups were found in: pregnancy rates; numbers of live, dead, or total fetuses; incidences of external, visceral, or skeletal

anomalies or variations; or body weight of live fetuses. The investigators surmised that this lack of an effect may hold true at any exposure level less than that which will kill a significant number of the dams by hyperthermia (colonic temperature greater than 40°C).

In a study designed primarily for seeking possible effects of chronic RFR exposure on mother-offspring behavioral patterns and the EEG, 33 female squirrel monkeys were exposed near the beginning of the second trimester of pregnancy to 2.45 GHz RFR at whole-body SARs of 0.034, 0.34, or 3.4 W/kg (the last value equivalent to about 10 mW/cm$^2$ of plane-wave RFR) for 3 hr/day, 5 days/week, until parturition. Eight pregnant monkeys were sham-exposed for the same periods. After parturition, 18 of the RFR-exposed dams and their offspring were exposed to RFR for an additional 6 months; then the offspring were exposed without the dams for another 6 months. No differences were found between RFR- and sham-exposed dams in the numbers of live births or in the growth rates of the offspring. The major difference between RFR- and sham-exposed offspring was that four of the five exposed at 3.4 W/kg both prenatally and after birth unexpectedly died before 6 months of age, but the mortality values were too small to place much confidence in statistical inferences. A follow-up study of mortality per se, which involved sufficient numbers of squirrel monkeys for adequate statistical treatment, did not confirm the RFR-induced offspring mortality results.

In summary, the studies showing demonstrable teratogenic effects following exposure to RFR have involved power density levels that are capable of producing a significant heat load in the animals. In general, the results indicate that a threshold of heat induction or temperature increase must be exceeded before teratogenic effects are produced. Because the heat-load increase in humans from RFR exposure at the average power densities outside the RS exclusion fence will be very small relative to the normal metabolic rate of about 1 to 2 W/kg, teratogenesis in humans from such exposure is not likely to occur.

C.3.4 Ocular Effects

The fear that RFR can cause cataracts is a recurring theme in newspapers and other popular media. Indeed, based on many investigations with animals by

various researchers, it is undoubtedly true that if a person's eyes were exposed to intensities high enough to elevate the temperature of the lens by about 5°C (9°F) or more, the lens would quickly suffer damage. The lens is the region of the eye most vulnerable to RFR because other regions have more effective means of heat removal, such as greater blood circulation, evidenced by much smaller temperature elevations in these regions than in the lens at the same incident power density. Therefore, the basic controversy regarding ocular effects is centered on whether exposure to much lower intensities (i.e., to power-density levels that would produce much smaller lens temperature elevations) for long periods of time, either continuously or intermittently, can cause eye damage. Implicit in this controversy is the issue of whether effects (if any) of long-term, low level exposure in the eye are cumulative.

## C.3.5 Humans

Some cases of ocular damage in humans ascribed to occupational exposure to RFR were reported during the 25 years after World War II. Although the exposure histories of these individuals could not be ascertained with any degree of certitude, their actual or incipient vision impairment probably resulted from exposure to average power densities substantially greater than the threshold found in animal studies (about 150 $mW/cm^2$).

The occurrence of cataracts in two editors with the New York Times was ascribed, in newspaper accounts during 1977 and 1978, to their exposure to supposed RFR from the cathode-ray tubes in video-display terminals used by them. Cases of RFR-induced birth defects and abortions were also linked, in other newspaper stories, to exposure to video terminals. The New York Times arranged for measurement surveys of the terminals in question. These surveys yielded negative results; the only measurable radiations emitted by the terminals were well above the RFR spectrum. Independent surveys of the same terminals by personnel from NIOSH confirmed these findings.

Epidemiologic studies conducted to determine whether prolonged exposure to RFR is cataractogenic have been negative.

## C.3.6 Animals

During the past 30 years, various investigations have been conducted on the effects of RFR exposure on the eyes of live experimental animals. Many of the results indicate that intraocular temperature increases of about 5°C or more are necessary for eye damage. Also, lens opacifications caused by RFR exposure alone were not produced at the same average power density when the eye was cooled during exposure.

Many of the results of RFR exposure indicate the inverse relationship between average power density and exposure duration for cataract formation and the existence of a threshold average power density of about 150 mW/cm$^2$ for single or multiple exposures for tens of minutes or more.

Several investigators compared the ocular effects of pulsed and CW RFR at equivalent average power densities. In representative investigations, the average power densities were greater than 100 mW/cm$^2$ and the exposures were for about 1 hr/day for several weeks. No significant differences between the effects of pulsed and CW RFR were found.

The existence of a cataractogenesis threshold implies that single or multiple exposure for indefinitely long durations at average power densities well below the threshold would not cause eye damage to humans or any other species.

In summary, based on the experimental results with animals indicating the existence of a threshold power density of 150 mW/cm$^2$ and on the finding of no statistically significant differences between exposed and control groups of humans on military bases, there is no evidence that prolonged exposure of humans to the RFR from the RS at the power densities outside the exclusion area is likely to cause eye damage.

## C.3.7 Studies of the Nervous System

Several types of studies have been conducted on effects of RFR on the nervous system of animals. These studies are considered particularly important in the USSR, where RFR is believed to stimulate the nervous system directly and thereby cause a variety of physiological effects. U.S. scientists tend to doubt that RFR interacts directly with the nervous system except,

possibly, under special circumstances (to be discussed later in this section); they consider most effects of RFR on the nervous system to be indirect results of other physiological interactions.

## C.3.8  RFR Hearing Effect

Humans in the vicinity of some types of pulsed radar systems have perceived individual pulses of RFR as audible clicks (without the use of any electronic receptors).  This phenomenon has attracted much interest-- especially in the United States--because it has often been cited as evidence that nonthermal effects can occur and because an initial hypothesis was that one possible mechanism for perception is direct stimulation of the central nervous system by RFR.  Various theoretical and experimental studies, the latter with both human volunteers and laboratory animals, have been conducted to determine the conditions under which pulsed RFR is audible and to investi- gate the interaction mechanisms involved.  Many of the results support the hypothesis that an RFR pulse having the requisite pulse power density and duration can produce a transient thermal gradient large enough to generate an elastic shock wave at some boundary between regions of dissimilar dielectric properties in the head, and that this shock wave is transmitted to the middle ear, where it is perceived as a click.  Persons with impaired hearing are unable to hear such clicks, and experimental animals in which the cochlea (the inner ear) has been destroyed do not exhibit brainstem evoked responses.

Investigators used 3.0 GHz RFR to study the auditory effect in two cats, two chinchillas, one beagle, and eight human volunteers.  For the animals, surface or brainstem-implanted electrodes were used to measure the responses to RFR pulses and the responses evoked by audio clicks from a speaker. They found that perception of 10-microsecond pulses required pulse power densities of at least 1.3 $W/cm^2$ for both cats, 1 and 2 $W/cm^2$ for the two chinchillas, and 300 $mW/cm^2$ for the beagle.

The eight humans were given standard audiograms.  Because such audiograms do not test hearing above 8 kHz, binaural hearing thresholds were also determined for seven of the subjects for frequencies in the range from 1 to 20 kHz.  Five of the subjects could detect 15 microsecond pulses as clicks; the other three required a pulse duration of 200 microseconds for

perception. No correlation between the results and the audiograms was apparent; however, there was a strong correlation between RFR perception and hearing ability above 8 kHz as determined from the binaural thresholds. The average threshold pulse power density for 15 microsecond pulses was about 700 mW/cm$^2$; however, three of the subjects were able to perceive 15-micro-second pulses at a pulse power density of 300 mW/cm$^2$, a value taken herein as representative for humans. Thus, humans at ground level outside the RS exclusion fence would not likely "hear" the RFR pulses. It should be noted that these investigators exposed the human volunteers to pulse power densities as high as 2,000 mW/cm$^2$ without apparent ill effects.

## C.3.9 Calcium Efflux

Exposure of brain-tissue samples from newly hatched (neonatal) chicks to RFR amplitude-modulated at low frequency has been reported to increase the rate of exchange of calcium ions between the tissue and the fluid bathing it. This effect has been demonstrated by two groups of investigators for modulated carrier frequencies of 50, 147, and 450 MHz, as well as for exposure to the modulation signal (16 Hz) alone, but not for unmodulated 50, 147, or 450 MHz RFR. Incident power densities that are effective in altering the rate of calcium exchange lie between approximately 0.1 and 3.6 mW/cm$^2$. However, within this range, not all power densities are effective. There appear to be narrow, effective power-density "windows." Calculations of internal field intensity appear to indicate that this factor is important in predicting effectiveness. The mechanisms whereby modulation effects are mediated are speculative. Of additional interest is a report that 16 Hz amplitude-modulated 147 MHz RFR at 2.0 mW/cm$^2$ increases calcium efflux from pancreatic tissue slices to approximately the same extent as that from neonate chick brain tissue incubated and exposed under similar conditions. An attempt to obtain alterations in calcium efflux from rat brain tissue by use of pulse-modulated 1 GHz RFR was unsuccessful. It is uncertain whether these negative findings were a result of differences in brain tissue, exposure parameters, carrier frequency, or type of modulation.

All of the above studies were carried out on isolated tissues maintained in physiological solutions. A recent study has reported that similar alterations in calcium ion exchange occur for exposed brains of paralyzed live

cats irradiated at 3 mW/cm$^2$ with 450 MHz RFR sinusoidally amplitude modulated at 16 Hz.

The effect is scientifically interesting in that it represents a rare instance where RFR may be producing a biological effect by processes other than thermal mechanisms. Interpreting these results with regard to human health and safety is difficult. First, the phenomenon is subtle. Large numbers of samples have to be processed to show a statistically significant effect. Second, the observations are highly variable and difficult to repro-duce. Third, the circumstances of the experimental methodology are such that the observations of changes of calcium exchange appear to apply to the surface region of the brain rather than to the brain as a whole. Finally, the phenomenon depends on the amplitude modulation of the RFR in a narrow fre-quency band around 16 Hz and occurs only for narrow ranges of average power densities (windows) between 0.1 and 3.6 mW/cm$^2$. Nevertheless, because this range is above the levels of general public exposure from the RS and the system is not modulated in this manner, the occurrence of this effect in humans is unlikely.

C.3.10  **Blood-Brain Barrier Effects**

In most organs and tissues of the body, molecules in the blood can freely diffuse into the tissue around the capillaries. However, presumably to protect the brain from invasion by various blood-borne microorganisms and toxic substances, large molecules such as proteins or polypeptides exhibit little or no movement from the blood into the surrounding brain tissue in most regions of the brain. The exact manner by which the movement is prevented is still conjectural, but the process is referred to as the "blood-brain barrier" (BBB). The BBB can be "opened" by certain agents (e.g., ionizing radiation, heat) or chemical substances (e.g., DMSO). Studies have been conducted to examine whether RFR also can alter the BBB permeability of animals to various large molecules.

Four studies by two separate research groups have reported gross permeability increases in the rat BBB when the brain temperature was raised significantly (e.g., several degrees) by RFR heating, or, equivalently, the local SAR was several hundred watts per kilogram. Other researchers found

scattered regions in the brain displaying permeability changes for 2-hr exposure at 10 mW/cm$^2$. Twenty percent of the sham-exposed animals also showed these changes, which were reversible. The 10 mW/cm$^2$ value may represent the lower limit at which local regions of the brain are heated.

One study reported alterations in BBB permeability to fluorescein by use of pulsed RFR at average power densities as low as 0.2 mW/cm$^2$. These findings could not be repeated by three other groups using fluorescein and similar experimental procedures.

Another study reported increased BBB permeability to radiotracer-labeled molecules at average power densities less than 3 mW/cm$^2$, with pulsed RFR more effective than CW RFR. Three other research groups could not repeat these findings. Subsequently, the researchers first reporting the effect used a higher average power density (15 mW/cm$^2$) and different techniques, and showed that their original findings could be explained as an increase in local cerebral blood flow rather than as an increase in BBB permeability. (Local cerebral blood flow can be altered in humans by mental activity in the absence of external physical stimuli.)

In summary, RFR can alter BBB permeability at exposure levels sufficient to cause heating of the brain. Exposure to levels considered insufficient to cause heating (below several mW/cm$^2$) has also been reported to alter BBB permeability, but these results have not been confirmed, despite several independent attempts to do so. In one case, the original findings may have arisen as a consequence of the experimental techniques used. On the basis of the evidence available, it is very unlikely that exposure of people to the levels of RFR existing at ground level outside the exclusion fence of the RS would have any effect on the permeability of the BBB.

C.3.11   Histopathology and Histochemistry of the Central Nervous System (CNS)

Histopathology is defined as the study of diseased or damaged tissues, and histochemistry as the study of the chemical composition of various tissues. Studies of histopathological effects of RFR on the brain have been conducted in both the United States and the USSR. Studies in the USSR have covered a wide range of frequencies, but the dosimetry and methods were inadequately reported in many instances. Exposure of animals (predominantly

rats) to RFR between 500 MHz and 1 GHz (no additional information on frequency) at 10 mW/cm$^2$ for 1 hr/day for 10 months resulted in various changes from the normal appearance of nerve cells of the brain, as detected by delicate elective neurohistological methods (not otherwise specified). The authors reported that the power density did not raise body temperature, but current knowledge indicates that the method of exposing the animals was such that the SAR must have varied considerably among the animals. The reported changes in appearance were similar to those found in other experiments of a frankly thermal nature (20 to 240 mW/cm$^2$), and it is most probable that the reported effects in the chronic exposure experiments were also of thermal origin.

In the United States, a study of the histopathological effects of RFR on the brain was performed on hamsters exposed to 2.45 GHz RFR at power densities between 10 and 50 mW/cm$^2$ for periods between 30 min and 24 hr. Chronic exposures were also carried out at similar power densities over a period of 22 days. In this study, pathological changes were found only in the hypothalamus and subthalamus, two regions near the center and base of the brain. Comments after oral presentation of this study noted that the nature of RFR absorption inside the skull of such a small animal at the frequency used could lead to regions in the brain where the SAR would be tens of times higher than that expected from the nominal power density and that rectal temperature measurements in the animals would not reflect such a condition. The observed pathological effects seem likely to have resulted from thermal processes. Quantitative studies on the effects of RFR at relatively high levels (10 to 46 mW/cm$^2$, SAR approximately 2 W/kg) on rat Purkinje cells of the cerebellum (a distinctive cell type in this region of the brain) showed that RFR exposure pre- and postnatally caused a significant decrease in numbers of these cells. However, a similar study using squirrel monkeys did not show such an effect. Size differences between the heads and brains of the rat and squirrel monkey may have resulted in high local SAR in regions of the rat brain, but not in similar regions of the squirrel monkey brain, again indicating that the observed effects seem likely to have resulted from thermal processes.

Two studies were reviewed that examined effects of RFR on brain neurochemistry. One showed no effects on specific neurotransmitters of mouse brain at 19 MHz for near-field exposure conditions of 6 kV/m (E field) or of 41 A/m (H field) for 10 min. The other showed a sequence of small (5 to 10%) changes of biochemical activity in subcellular components associated with tissue respiration at exposure levels of 5 and 13.8 mW/cm$^2$. The significance of these latter findings is unclear, but they are unlikely to be indicative of a hazard because of the wide range of tissue respiration values possible under various environmental and activity situations.

In summary, RFR can cause observable histopathological changes in the CNS of animals, but these changes appear to be thermal in nature. Under special conditions of frequency and skull size, a focusing effect can be obtained in small rodents, causing local SARs tens of times higher than would normally be expected from whole-body SAR measurements. Such conditions do not occur for the adult human skull. One study has reported small changes in brain-tissue respiratory chain function at a power density of 5 mW/cm$^2$. It is unlikely that such effects would be detectable at the power densities at ground level outside the RS exclusion fence. These studies provide no evidence that exposure to such power densities are likely to be hazardous.

## C.3.12 EEG Studies

Studies have been conducted to ascertain the effects of RFR on the EEG or other related electrophysiological properties of the CNS. For EEG measurements made after RFR exposure, the time consumed in placing and attaching the electrodes and the variability of placement introduce problems of interpretation. Additionally, if the effects are transient, they may stop when exposure ceases. For studies attempting to measure EEG changes during application of the RFR, the electrodes and leads used to pick up EEG signals also pick up electrical signals directly from the fields, causing artifacts that render the recordings difficult to interpret. In addition, implanted or chronically attached electrodes will perturb the electric fields in their vicinity and produce great enhancement of energy absorption, thereby creating still another artifact in the biological data. To meet these problems, specially designed implant electrodes of high-resistivity materials that do not cause field

perturbation have been constructed and used in a few of the more recent studies.

Two groups of researchers, using implanted metallic electrodes, reported changes in EEG patterns after acute or chronic exposure of rabbits to RFR. Another group, using implanted electrodes made of carbon instead of metal (an attempt to avoid the field distortion artifact), reported no significant differences in EEG between irradiated and control rabbits after 3 months of RFR exposure (1.5 mW/cm$^2$, hr/day). Another study, using electrodes externally placed after exposure rather than indwelling ones, reported no differences in EEG pattern between control and RFR-exposed monkeys after more than 12 months of exposure. A study of rats exposed to RFR from before birth to age 92 days (indwelling electrodes again not used) showed no differences from control animals when both groups were tested at 140 days of age. Lastly, the EEGs of rabbits having indwelling carbon-loaded Teflon (high resistance) electrodes were examined before and during exposure to 2.45 GHz RFR at 100 mW/cm$^2$ (SAR of about 25 W/kg at the electrodes), and no obvious differences were found.

In summary, the use of implanted metallic electrodes in studies of the effects of RFR on the EEG or on evoked potentials of the CNS may be questioned as a procedure likely to introduce artifactual effects in the preparation under study, as well as in the recordings themselves. These artifacts may be minimized by use of electrodes appropriately designed from high resistivity materials. Experiments in which such specially constructed electrodes were used, or in which electrodes were applied after exposure, show no evidence of statistically significant differences in EEGs or in evoked responses between control and RFR-exposed animals. There is no evidence that ground-level RFR from the RS is likely to cause any effects on the EEG or evoked potentials of populations outside the exclusion fence. Based on the study, persons with implanted metallic electrodes in the brain or prosthetic metallic plates on the skull may have effects induced in their EEGs or evoked potentials inside the exclusion fence, where the highest average power densities for the system is less than 1.0 mW/cm$^2$ but only if they were there for extended periods (several months).

## C.3.12 Effects on Behavior

Many experimental studies have been conducted on the effects of RFR on animal behavior. The results of such studies are considered particularly important in the USSR, where they are often considered to be evidence for direct effects of RFR on the CNS. Scientists in the United States do not always agree that behavioral effects necessarily imply direct effects on the CNS. However, behavioral effects are very sensitive indicators of biological function and hence receive appropriate attention in both Eastern European and Western countries. The papers described in the RFR-bioeffects review were selected as representative of the types of behavioral studies that have been conducted. These include studies of effects on reflex activity, RFR-perception studies, evaluations of effects of RFR on learning and on performance of trained tasks, studies of interactive effects of RFR and drugs on behavior, and investigations of behavioral thermoregulation. Studies have been conducted on mice, rats, rabbits, squirrel monkeys, rhesus monkeys, and humans.

Soviet studies have claimed that exposure of rats to RFR at power densities as low as 0.01 $mW/cm^2$ for 10 days or more have resulted in disturbance of many inborn forms of behavior, including conditioned reflex activity. The validity of these claims is difficult to assess, however, because the reports of the experiments lack details. Attempts were made to repeat the studies in the United States, but using higher densities. No effects on reflex development were seen at power densities up to 10 $mW/cm^2$ for durations up to 92 days. Soviet reports of effects at low (equal to or less than 0.5 $mW/cm^2$) power densities under long-term exposure conditions and the absence of similar effects in the same or higher power-density range in the studies of U.S. researchers have appeared frequently in the RFR-bioeffects literature.

The RFR hearing effect is, by definition, perception of pulsed RFR. Other studies with CW or modulated RFR have been conducted to determine whether perception can serve as a behavioral cue, and some studies have indicated that rats modify their behavior in response to pulsed RFR at average power densities as low as 0.2 $mW/cm^2$. As discussed, however, average power densities are meaningless in the perception of pulsed RFR. Pulse power density is the meaningful parameter, and humans appear to be able to perceive

pulse power densities of about 300 mW/cm$^2$ and higher. By contrast, CW RFR is an extremely feeble perceptual cue, with tens of milliwatts per square centimeter (average power density) necessary to modify behavior, unless the RFR is accompanied by other perceptual cues such as light or sound. This is borne out in studies on humans, where the threshold for perception of warming of the skin is 27 mW/cm$^2$.

Acute exposure to RFR will suppress performance of learned tasks and the learning of new tasks in rats, squirrel monkeys, and rhesus monkeys at sufficiently high power densities (generally 5 mW/cm$^2$ and up). The effect depends on duration of exposure, animal species, frequency of RFR, power density, and demand characteristics of the behavior. A reasonable conclusion is that suppression of learned behavior tasks depends on the amount and distribution of energy absorbed by the animal. Chronic exposure produces similar results but with a slight reduction in minimum power density required (1 mW/cm$^2$ and up).

Studies on the interaction of RFR and drugs in rats that affect the CNS have yielded interesting results. Pulsed 2.45 GHz RFR at an average power density of 1 mW/cm$^2$ (SAR of 0.2 W/kg) was found to enhance the effects of dextroamphetamine, a CNS stimulant, and chlordiazepoxide and phenobarbital, CNS depressants. By contrast, pulsed 2.8 GHz RFR at 1 mW/cm$^2$ did not produce any alterations in the behavioral dose-effect functions of chlorpromazine or diazepam, two other commonly prescribed CNS depressant drugs. Mechanisms of this synergism between RFR and certain drugs, but not others, are unclear at present.

Studies specifically designed to examine thermoregulatory behavior in rats and squirrel monkeys, using 2.45 GHz RFR, have shown alterations in behavior at power densities from 5 to 20 mW/cm$^2$ in the rat and at 6 to 8 mW/cm$^2$ in the squirrel monkey. In addition, mice have been shown to orient themselves to reduce the percentage of RFR energy absorbed where they might otherwise have become overheated. Behavioral thermoregulation depends on the existing environmental situation. The 5-mW/cm$^2$ level appears to be the threshold value necessary to elicit a behavioral thermoregulatory response.

In summary, RFR is capable of producing alterations in a wide variety of behaviors of various species of animals. Except for pulsed RFR, average power densities required to modify behavior are almost all at levels of approximately 5 mW/cm$^2$ and above, and most appear to be in the thermal range. Perception of pulsed RFR as sound is a peak-power phenomenon, not one of average power. It is difficult to relate most of the behavioral studies in animals to humans. All behavioral studies are directly relevant to the nature of the species being studied, and the conclusions of a given study do not readily transfer to other species. Because of the power densities needed to cause reported effects, however, these studies provide no evidence that exposure to RFR at the levels outside the RS exclusion fence is likely to have adverse effects on human behavior.

C.3.13  Endocrinological Effects

Exposure of animals to RFR has produced somewhat inconsistent effects on the hormone-secreting (endocrine) system of mammals. In general, the effects produced appear to be related to either the heat load associated with the RFR or the stress induced in the animals by the RFR and, possibly, other experimental circumstances. Some effects also appear to be related to alteration of the circadian rhythm by RFR. There do not appear to be any effects clearly demonstrated to be associated with nonthermogenic stimulation of the endocrine system or the associated parts of the CNS.

Because of the known sensitivity of the testes to heat, several investigations of the effects of RFR on gonadal function have been conducted. In one early study, mice were exposed to 9.27 GHz RFR at 100 mW/cm$^2$ for 4.5 min/day (which increased mean body temperatures by 3.3°C) for 5 days/week over 59 weeks. Testicular degeneration was found in 40% of the RFR-exposed and in 8% of the control mice that had died during the course of the experiment. Recently, other investigators reported that exposure of mice to 2.45 GHz RFR at 20 to 32 mW/cm$^2$ for 16 hr/day for 4 days had no effect on sperm count or percentages of abnormal sperm.

In another recent investigation, the rear halves of anesthetized mature male mice were exposed to 2.45 GHz RFR for 30 min at half-body SARs ranging from 18 to 75 W/kg, which produced elevated rectal temperatures. For

comparison, the rear halves of other anesthetized mice were immersed for 30 min in a well heated bath to yield comparable rectal temperatures. Extensive degeneration of the sperm-generating cells was evident for RFR exposure at 75 W/kg and for well heating to 45°C. At SARs of 37 W/kg or lower or a well temperature of 37°C, no effects were seen. Measurements of testicular temperature indicated the existence of a threshold of about 39°C for depletion of spermatocytes and of about 41°C for 50% cell death after 6 days of RFR exposure or direct heating. The corresponding SARs for these two thresholds were 20 and 30 W/kg.

Men occupationally exposed to RFR in the 3.6 to 10 GHz range at power densities of tenths to hundredths of a $mW/cm^2$ for 1 to 17 years (a mean of 8 years) were reported to show slightly reduced sperm counts, but normal plasma levels of hormones that control the functioning of the gonads.

Stimulatory effects on the thyroid glands of dogs were obtained from local exposure of one of the two thyroids to 2.45 GHz RFR for 2 hr at 72, 162, or 236 $mW/cm^2$. The SARs in the exposed gland were 58, 121, and 190 W/kg, respectively, and the corresponding temperatures were about 102, 106, and 113°F. In response, the exposed glands increased their output of thyroxine (a hormone that controls the metabolic rate in other cells) by factors of 1.5, 3.5, and 10, an effect attributed to the temperature rise. At the levels of RFR outside the RS exclusion fence, no temperature rise would occur; therefore, this effect would be absent.

The necessity for minimizing stresses induced in rats by factors other than RFR by allowing them to become accustomed to the experimental situation ("gentling" them) before RFR exposure was demonstrated in several investigations. With the use of such a procedure, endocrinological effects ascribable to RFR exposure can be more readily discerned from those due to non-RFR stresses, but the latter are difficult to eliminate entirely. In a recent study, gentled rats were exposed to 2.45 GHz RFR at power densities ranging from 1 to 70 $mW/cm^2$ (equivalent SARs of 0.21 to 14.7 W/kg) for periods ranging from 1 to 8 hr at an environmental temperature maintained at 24°C. Sham-exposed rats were used as controls. After treatment, the rats were decapitated, colonic temperatures were taken, and blood was collected for assays of thyroxine, thyrotropin (a hormone secreted by the pituitary gland),

growth hormone (also secreted by the pituitary), and corticosterone (secreted by the adrenal gland). For exposures of 1 hr, colonic temperatures increased with power density at 20 mW/cm$^2$ and higher, but consistent elevation of serum corticosterone did not occur below 50 mW/cm2 Lower serum thyrotropin and growth hormone levels also occurred at this and higher power densities. For sham exposures and exposures at 1-20 mW/cm$^2$ for longer durations (2-8 hr), the results were rather equivocal, presumably because such exposures encompassed significant portions of the circadian cycle.

Exposure of warm-blooded animals to RFR has been found to affect their involuntary thermoregulatory mechanisms. In a recent study, squirrel monkeys were exposed to 2.45 GHz CW RFR for 10 min or 90 min in relatively cool ambient temperatures of 9, 68, or 77°F. The power densities ranged from 2.5 to 10 mW/cm$^2$ (SARs from 0.4 to 1.5 W/kg). The metabolic heat production was calculated from the oxygen deficit in the expired air of each monkey. At all three ambient temperatures each monkey at 6 mW/cm$^2$ reliably initiated a reduction of 4 mW/cm$^2$ of metabolic heat production, and the magnitudes of the reduction were linear functions of the power density above the threshold values.

This investigator also exposed squirrel monkeys to RFR in ambient temperatures ranging from about 90 to 95°F. After an initial 90-min or longer equilibration period, each monkey was exposed for 10-min periods to power densities in an increasing sequence from 2.5 to 20 mW/cm$^2$, with sufficient time between exposures for reequilibration. The results indicate that at ambient temperatures below about 97°F, at which sweating in a sedentary monkey may occur spontaneously, the threshold power density (or SAR) for initiating thermoregulatory sweating decreased with decreasing ambient temperature.

In summary, although some of the effects of RFR exposure on the endocrine system appear to be relatively straightforward and predictable from physiological considerations, other, more subtle effects require further study, notably those related to the interactions among the pituitary, adrenal, thyroid, and hypothalamus glands and/or their secretions. Part of the problem in interpreting results appears to arise from uncertainties regarding stress mechanisms and accommodations thereto. Animals placed in novel situations are much more prone to exhibit stress responses than animals that have been

adapted to the situation. However, there may be large variations in adaptation among animals in a given situation or among experimental situations in different laboratories.

In conclusion, because the reported effects of RFR on the endocrine systems of animals are largely ascribable to increased thermal burdens or stresses engendered by the experimental situation, or both, there is no evidence that such effects would occur in humans exposed to the RFR from the RS outside the exclusion fence.

C.3.14  Immunological Effects

Reports accumulated to date indicate that RFR has quite definite effects on the immune system of mammals. Most of the reported effects were detected after exposure at power density levels of about 10 mW/cm$^2$ and higher; a few were detected following exposure to power densities as low as about 0.5 mW/cm$^2$; and in some cases, effects obtainable with the higher power-density range were not found at lower power densities. In most studies, the mechanisms for the effects seen were not investigated, and the various reports are somewhat inconsistent. Because of the complexity of the immune system and the variety of test procedures used, the representative studies discussed in this subsection are grouped into appropriate categories.

C.3.15  *In Vitro* Studies

An important question is whether human or animal lymphocytes (a type of white blood cell of key importance in the immune system) can be stimulated by RFR exposure to transform into lymphoblasts (mitotically active form of lymphocytes) and undergo cell division (mitosis). *In vitro* studies directed toward this question are those in which lymphocytes are removed from the body, cultured, exposed to RFR (or exposed, then cultured), and examined for RFR-induced effects. Usually such cells are cultured in the presence of a mitogen (an agent, usually chemical) that stimulates blastic transformation (i.e., lymphocyte to lymphoblast) and cell division.

One of the early investigators cultured specimens of human lymphocytes, added the mitogen phytohemagglutinin (PHA) to one set of specimens, and exposed groups from both sets to 2.95 GHz pulsed RFR at an average power density of either 7 or 20 mW/cm$^2$ for various durations. The results for the

PHA-stimulated cultures showed no significant changes in percentages of blastoid forms, but there were significant decreases in percentages of lymphocytes and increases in the mitotic index correlated with exposure duration. However, another investigator endeavored to repeat these experiments with human lymphocytes, but encountered difficulties in obtaining reproducible results. He implicated uncontrolled temperature increases in the specimens (which were not cooled during exposure) as the problem.

In a representative recent study, bone marrow cells from mice were prepared and exposed at constant temperature to 2.45 GHz RFR for 15 min at 30 to 1000 mW/cm$^2$ (SARs of 60 to 2000 W/kg). Similar specimens were sham-exposed. Cell samples were then treated with a colony stimulating factor, permitted to grow in an appropriate medium, and examined on days 5-7 and 12-14 following exposure. No significant differences were found at either time between the number of colonies from sham-exposed samples and from the samples exposed at 30 mW/cm$^2$ (SAR of 60 W/kg). However, at higher power densities, the ratio of the number of colonies from RFR-exposed to sham-exposed samples was found to decrease with increasing power density.

In another investigation, bone marrow specimens from children with acute leukemia in remission or other disorders were similarly exposed. Again, no significant differences between RFR- and sham-exposed specimens were obtained at 31 and 62 mW/cm$^2$ (SARs of 62 and 124 W/kg). Thus, negative results are obtained when the temperature of the cell suspension is held constant (at 37°C) during RFR exposure.

C.3.16 *In Vivo* Studies: Acute Exposures

In most *in vivo* investigations involving acute (i.e., short-duration) exposures, live animals were exposed one time for a period typically ranging from a few minutes to an hour at power densities high enough to produce substantial temperature increases in various tissues or organs or of the body as a whole. In general, the effects of such acute RFR exposure on the immune system appear to be stimulatory. The number of circulating lymphocytes in the blood increases, as does the ability of the immune system to manufacture antibodies to foreign substances. The number of cells involved in production of immune complement (a complicated series of interacting chemicals in the

blood) also increases. The mechanisms of those effects are not completely understood, but in some cases they may be a secondary result of the stress induced in the animals by the RFR-produced heat or by other stresses, such as from handling.

In a study selected to illustrate the complexity of this topic, mice were exposed to 2.45 GHz RFR for 30 min/day at 5 to 15 mW/cm2 (SARs of 3.7 to 11 W/kg) for 1 to 17 days, after which the spleens were removed and cells therefrom were cultured for 72 hr with or without one of several mitogens. Tritiated thymidine, a radioactively labeled substance whose uptake is an indication of the DNA synthesis involved in cell proliferation, was added 4 hr before the end of the culturing period. The cells were then harvested and assayed for thymidine uptake. Plots of uptake versus exposure duration showed biphasic or cyclical responses for cells from both mitogen-stimulated and nonstimulated cultures from the RFR-exposed mice. The investigators suggested that such cyclical fluctuations could account for the differences in results from various laboratories. However, similar plots for the sham-exposed mice also showed cyclical fluctuations, evidently resulting from factors other than RFR, such as circadian rhythms and estrus-cycle changes in female mice; therefore, it was impossible to ascertain the proliferative effects of RFR per se. In another part of the study, RFR exposure at 15 mW/cm$^2$ for 5 days (30 min/day) did not diminish the effectiveness of lymphocytes against leukemic cells injected after, or concurrently with, the last exposure.

In a series of investigations, exposure of mice to thermogenic levels of RFR produced increases in the numbers of splenic B-lymphocytes (one of several subclasses). There is also experimental evidence for the existence of a threshold energy absorption (about 10 J/g) for this effect and for the dependence of the effect on genetic factors.

C.3.17  *In Vivo* Studies: Effects of Chronic Exposures on Immunological Parameters

In many investigations involving chronic (long-term) exposures of animals to RFR, changes in various components of the immune systems of usually healthy animals are sought, under the often tacit assumption that such changes could be detrimental (or perhaps beneficial) to the subjects exposed. Invest-

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igations of this kind are discussed next. Other *in vivo* investigations are directed toward determining whether chronic exposure to RFR actually alters the incidence or severity of diseases imparted to the subjects. Studies of the latter kind are described in the next section.

In a representative early study, exposure of mice to pulsed 2.95 GHz RFR at an average power density of 0.5 mW/cm$^2$ for 2 hr/day, 6 days/week over 6 weeks was reported to cause general stimulation of the immune system. This effect diminished when the exposure was extended to 12 weeks, suggesting that the mice were adapting to the RFR.

Most of the recent investigations involving chronic exposure showed no significant alterations of the immune system. In one such study, pregnant mice were exposed to 100 MHz CW RFR for 4 hr daily from day 6 of pregnancy to parturition. On birth, several male pups were exposed similarly until age 20-22 days, others until 40-42 days, and the remainder until 97 days. No significant differences in counts of red blood cells, counts of the various types of white blood cells, or the other standard blood tests were found between blood samples of RFR- and sham-exposed rats taken at ages 22 and 42 days. In addition, stimulation by mitogens produced no significant differences in lymphocyte response. The pups removed at age 22 days were immunized with purified pneumococcal polysaccharide. Blood samples taken 5 days later showed no significant differences in antibody levels of RFR- and sham-exposed rats.

In another study, rats were exposed for 22 hr/day over their entire lifetimes to circularly polarized, pulse-modulated 2.45 GHz RFR at peak and average power densities of 125 and 0.5 mW/cm$^2$ respectively. These exposure values were selected to simulate, by scaling considerations, chronic exposure of humans to 450 MHz RFR at an average power density of 1 mW/cm$^2$. The results indicated no significant differences between RFR and sham-exposed rats in immunological parameters.

## C.3.18 *In Vivo* Studies: Effects of Chronic Exposures on Health and Disease

Relatively few studies have been conducted to determine whether chronic exposure to RFR alters the resistance to, or the severity of, diseases accidentally acquired or purposely given to animals. Such studies have been difficult to conduct, and reliable, consistent results have been hard to achieve.

In an early study, the investigators observed that mice exposed to 9.3 GHz pulsed RFR at 100 mW/cm$^2$ average power density for 4.5 min/day over 59 weeks appeared to have more resistance than controls to a pneumonia infection accidentally introduced into the colony; however, this was an incidental observation, not the results of a planned experiment.

Subsequent studies yielded mixed results, some indicating that RFR exposure is beneficial and others that it is detrimental to the animal challenged with specific pathogens. However, the results of both kinds indicate that the effects were essentially due to the heat produced by the RFR.

In a recent study, groups of mice were immunized against *Streptococcus pneumoniae* and then sham-exposed or exposed 2 hr/day for 5 successive days to 9 GHz pulsed RFR at an average power density of 10 mW/cm$^2$ (calculated SAR of 3.3-4.7 W/kg). Another group injected with saline but not exposed served as controls. On day 6 after immunization (the day after exposure), blood samples were taken for various tests, the mice were challenged with a dose of virulent streptococcus that is normally fatal to 50% of the mice, and the number of deaths per day were noted for 10 days after challenge. The RFR-exposed mice had significantly higher levels of circulating antibodies (about 28%) than the sham-exposed mice, but there were insignificant differences between the groups in red and white blood cell counts or other standard blood tests. No antibodies were detected in the saline-injected mice. Ten days after challenge, 25 of the 53 RFR-exposed mice and 27 of the 54 sham-exposed mice had died, a nonsignificant difference. However, the greatest number of deaths in one day in the RFR-exposed group (10) occurred on day 6, whereas 14 of the deaths in the sham-exposed group occurred on day 3. The authors suggest that the RFR caused a greater initial neutralization of the pathogens, but not

enough to produce complete recovery.  No saline-injected mice survived the challenge.

## C.3.19  Summary of Immunological Effects

RFR does appear to have profound effects on the immune system of mammals. Some of the reported effects were contained at low power-density levels, but most of the studies were performed at relatively high power densities; in some cases, effects obtained at high power densities were not found at lower power densities, suggesting the possibility that power density thresholds exist. Some of the results indicate immunosuppressive effects; some indicate immunostimulative effects, and others, both kinds of effects.  Also, results from various laboratories obtained under apparently comparable conditions are sometimes contradictory, an indication of the probable presence of uncontrolled factors or subtle differences in the experimental protocols. Based on current findings, it appears that *in vivo* RFR-induced effects on the immune system are dependent to varying degrees on the ages of the experimental subjects, the frequency and average power density of the RFR (or the whole-body SAR resulting therefrom), the exposure duration and perhaps the time of day when the exposures are given, the kind of exposure system used (which affects the internal SAR distributions within the animals), and the kind of endpoint analyses undertaken and when they are performed relative to the completion of exposures.

Reported *in vivo* effects on the immune systems of animals from chronic exposure to RFR at average power densities below 1 mW/cm$^2$ are unlikely to be linked simply to temperature increases, but such results have not yet been replicated elsewhere.  In most other in vivo investigations, such as those discussed herein, the exposures were at average power densities exceeding 1 mW/cm$^2$.  The existing evidence indicates that some of the immune-system effects are probably mediated through the effect of RFR on the endocrine system, involving the general syndrome of adaptation to stress. The mechanisms and significance of such effects are not yet understood, nor have individual findings been independently verified.  There is currently no evidence that reported RFR effects on the immune systems of animals would occur in humans chronically exposed to the levels of RFR from the RS outside the exclusion fence, or that such effects would be hazardous to human health.

## C.3.20 Biochemical and Physiological Effects

The literature on biochemical and physiological effects associated with RFR is extensive. Many of the reported effects are associated with other events (e.g., changes in hormonal levels or stress adaptation), some are questionable for various reasons, and others do not have a clear medical significance.

### C.3.20.1 *In Vivo* Exposure of Intact Animals

In the first of four studies with rhesus monkeys, 12 monkeys were exposed to 10.5 or 26.6 MHz pulsed RFR for 1 hr at average power densities of 200 or 105 $mW/cm^2$ respectively, or to 19.3 MHz RFR for 14 days, 4 hr/day, at 115 $mW/cm^2$. Hematologic and blood chemistry analyses indicated no statistically significant differences between exposed and control monkeys that could be ascribed to RFR. In another part of this study, exposure at increasing power densities up to 600 $mW/cm^2$ yielded no obvious indications of thermal stress, increases of heart rate, or other influences on the electrical events of the heart cycle due to the RFR.

In the second study, male rhesus monkeys were exposed to 26 MHz CW RFR at 500, 750, or 1,000 mW/cm2 for 6 hr. Measurements of skin and rectal temperatures indicated that even at the highest power density, the monkeys were in thermal equilibrium; i.e., they were able to dissipate the additional heat induced by the RFR, and their thermoregulatory mechanisms were quite efficient in doing so. Calculations by the investigators show that exposure of a 3.6-kg (about 7-lb) monkey to 26 MHz RFR at 1,000 $mW/cm^2$ is approximately equivalent to exposing a human 1.8 m (5 ft 11 in.) tall to this frequency at 400 $mW/cm^2$. The third study, performed at 15 and 20 MHz and power densities ranging from 760 to 1,270 $mW/cm^2$, yielded similar results.

The fourth was a follow-up study of 18 rhesus monkeys that had been exposed 1 to 2 years previously to 15, 20, or 26 MHz RFR for up to 6 hr on at least two occasions at power densities in the 500- to 1,270-$mW/cm^2$ range. Hematological and biochemical blood parameters were measured, and physical (including ophthalmologic) examinations were performed. No variations from normal values or conditions that could be attributed to RFR exposure were found.

In another primate study, the thermoregulatory system of the squirrel monkey, when stimulated by exposure to increasing levels of 2.45 GHz RFR, was shown to be quite effective in adjusting to the additional thermal burden or to decreases in environmental temperature.

Numerous studies have been performed on the physiological and bio-chemical effects of RFR in mice, rats, and rabbits. Among the effects reported were increases in oxygen-consumption rate, reduced food intake and blood glucose level, and other changes in blood chemistry indicative of thermal stress. In addition, stress-induced behavioral changes were observed.

In a representative study, mice were exposed to 2.45 GHz RFR under controlled environmental conditions for 30 min, during which the oxygen-consumption rate (a measure of the specific metabolic rate, SMR) and the SAR were determined at 5-min intervals. At the highest power used, the mean SAR decreased, during exposure, from 56 to 39 W/kg while the mean SMR decreased from 17.5 to 14 W/kg, thereby decreasing the mean total thermal burden from about 74 to 54 W/kg. Apparently, the mice endeavored to decrease their thermal burdens by altering their body configurations to minimize their RFR absorption rates.

In another investigation, rats were exposed to 918 MHz CW RFR at 10 mW/cm$^2$ (mean SAR of 3.6 W/kg) for 10 hr/day over 3 weeks. Physiological and behavioral comparisons between RFR- and sham-exposed rats showed no significant differences in fluid intake, body weight, rectal temperature, and corticosterone levels. However, food intake and blood glucose level were lower for the RFR-exposed animals, and their behavioral repertoires were altered, apparently to cope with the additional thermal burden imposed by the RFR. Two other similar investigations confirmed these findings, which indicate the existence of an SAR threshold between 0.9 and 3.6 W/kg for such effects. In consonance with this threshold are the results of another investigation in which mice were exposed to 8 MHz RFR at 0.5 mW/cm$^2$ (mean SAR of 0.013 W/kg; for 1 hr/day, 5 days/week for 10 weeks). Blood samples drawn at ages 28 through 600 days showed that the formed elements in the blood were not affected.

Another physiological effect reported was bradycardia (lower heart rate) in rats exposed to 2.45 GHz RFR for 30 min at relatively high SARs. Specifically, statistically insignificant bradycardia was observed in rats exposed at 4.5 W/kg; mild but statistically significant bradycardia developed within 20 min for those at 6.5 W/kg with recovery within about 2 hr; and pronounced bradycardia developed abruptly for those exposed at 11.1 W/kg, after which heart rates increased to values well above those of controls (tachycardia) and persisted at these levels to the end of the test period. These effects were evidently due to the excessive heat from the RFR.

None of these effects in intact live animals discussed above would be likely to occur in humans exposed to the RFR levels from the RS outside the exclusion fence.

## C.3.20.2 *In Vivo* and *In-Vitro* Exposure of Specific Tissues

Studies have been conducted to determine the physiological effects of RFR to various tissues either excised completely and kept alive artificially or accessed surgically and locally exposed in the live animal, with mixed and sometimes contradictory results.

One group of investigators reported that the contraction rate of excised segments of rat gut could be altered by exposure to 960 MHz RFR for 10 min at SARs of 1.5 to 5.5 W/kg. However, a similar study by another group did not confirm this finding.

Alterations of heart beat rate in excised turtle and frog hearts by exposure to RFR were observed by several investigators, but at either measurable heart temperature increases (e.g., 0.2°C) or heart SARs of 1.5 W/kg and higher. Another group of investigators surgically induced myocardial ischemia (inadequate blood flow rate to the heart) in the live cat and exposed the heart to 2.45 GHz CW RFR for 5 hr at an SAR of 30 W/kg. Although physiological differences between ischemic and nonischemic cats were evident, RFR exposure produced no significant changes in either group in mean arterial blood pressure, cardiac output, heart rate, EKG, or several subsequent heart tissue assays. These results indicate that local exposure of either the undamaged or ischemic heart to CW RFR in vivo at SARs as high as 30 W/kg has no effect on the myocardium or its neural components. These investigators

also exposed isolated atria of spontaneously beating rat hearts for 30 min to 2.45 GHz CW RFR at 2 or 10 W/kg. Measurements of contractile force and beat rate showed no significant differences between RFR- and sham-exposed specimens. All of these findings are at variance with those obtained from isolated turtle and frog hearts.

In 1968, exposure of isolated frog hearts to 1.425 GHz RFR pulses triggered synchronously with the EKG (200 ms after the peak of the R wave) was reported to produce significant tachycardia. However, in two subsequent studies by other investigators, this effect was not reproduced.

### C.3.20.3 *In Vitro* Cellular Effects

The principal technical problems in studying effects of RFR on cells in various media arise because such investigations are often conducted using conventional apparatus designed for cell studies--flasks, dishes, holders, agitators, water baths, incubators, and the like--and various elements of the apparatus may distort the field in such a way that the SARs of the cell cultures may be several fold higher or lower than field measurements indicate. Thus, the results of many investigations on RFR-induced effects on cell and tissue cultures are questionable. However, progress has been made in designing exposure apparatus for cell cultures that provide for accurate measurements of SAR in such cultures.

In 1974, researchers reported increases in membrane permeability of rabbit erythrocytes (red blood cells) and granulocytes (a type of white blood cell that contains granules in its cytoplasm) during in vitro exposure for up to 3 hr to 1 GHz RFR at power densities of 1 to 10 mW/cm$^2$. Other investigators subsequently showed that membrane permeability increases from RFR exposure were thermally induced. For example, suspensions of rabbit, human, and dog erythrocytes were exposed for 3 hr to 2.45, 3.0, or 3.95 GHz RFR at various SARs; the resulting suspension temperatures ranged from 25 to 44°C. The investigators also heated such cell suspensions in a water bath to comparable temperatures. As a representative result, they found no significant differences in membrane permeability between RFR-exposed suspensions and those heated to the same temperature. Researchers also found no significant

differences in the sequence and time course of mouse fibroblast cells heated to 43°C by RFR or water bath.

Exposure of *Escherichia coli B* bacterial cells in aqueous suspension to 2.6 to 4.0 GHz RFR for 10 hr at an SAR of 20 W/kg has no significant effect on their colony-forming ability or molecular structure.

C.3.21 Conclusions Regarding Biochemical and Physiological Effects

The thermal basis for most of the reported physiological and biochemical effects of *in vivo* exposure of intact animals to RFR is evident. Most significant with respect to possible hazards of human exposure to RFR are the investigations with nonhuman primates because their anatomies and physiological characteristics are closer to those of humans than are those of other experimental animals. The results with rhesus monkeys showed that exposure to RFR at frequencies in the high frequency (3-30 MHz) range at average power densities of the order of 100 mW/cm$^2$ were well within the thermoregulatory capabilities of this species. Also noteworthy were the negative findings of the blood-chemistry assays performed on rhesus monkeys 1-2 yr after exposures to such high power densities and the observations that the thermoregulatory system of the squirrel monkey is quite effective in compensating for RFR exposure.

The investigations involving exposure of intact, smaller species of mammals to RFR have yielded a variety of positive and negative results. Some of the positive findings are also clearly due to the additional thermal burden imposed by the RFR. Other results, involving decreased food intake and lower blood glucose levels in rats, indicate the existence of an SAR threshold of about 1 W/kg or higher for such effects.

One physiological aspect of concern is whether exposure of humans to RFR can affect their heart function. In early work on this subject with excised turtle, frog, or rat hearts, various investigators reported RFR-induced bradycardia, tachycardia, or both (depending on average power densities, with bradycardia for the lower range of power densities used). The lowest SAR at which bradycardia was observed in the isolated turtle heart was 1.5 W/kg. More recently, no RFR-induced changes were found in beat rate or contractile

force in isolated atria of rat hearts exposed to 2.45 GHz CW RFR at 2 or 10 W/kg.

The possibility that pulsed RFR at pulse rates that are synchronous with various periodic characteristics of the EKG may alter the heart rate was also investigated. Significant tachycardia in isolated frog hearts induced by pulsed RFR was reported in 1968. However, subsequent investigators were unable to reproduce this effect.

SAR-dependent changes in heart beat rate in intact animals were also reported. The results indicate the existence of a threshold between 4.5 and 6.5 W/kg.

Investigators found no significant changes in the mean arterial blood pressure, heart rate, and colonic temperature of unanesthetized rats exposed to CW RFR at 10 mW/cm$^2$ and no differences in various blood-chemistry parameters. These investigators also compared the results of *in situ* RFR exposure of cat hearts with and without myocardial ischemia, and found no significant differences ascribable to the RFR, an indication that RFR at the levels used does not affect the functioning of already damaged hearts.

The preponderance of results indicates that pulsed RFR synchronized with elements of the EKG does not alter the heart beat rate. Some of the results indicate that CW RFR does not alter heart function, and others that it does. However, most of the results, both positive and negative, support the conclusion that the effects occur at relatively high average power densities (above 1 mW/cm$^2$) or SAR values (above 1 W/kg). The same conclusion is applicable to the *in vitro* cellular effects discussed in the previous section, which were obtained at much higher SARs than those in the tissue preparations. Thus, the occurrence of physiological or biochemical effects from exposure to the RFR from the RS at the levels outside the exclusion fence is very improbable.

## C.4  MISCONCEPTIONS

Several misconceptions regarding the bioeffects of RFR continue to be expressed in popular accounts outside peer-reviewed scientific publications on

the subject. Those accounts tend to be sources of some confusion for the nonspecialist. The following are representative examples.

The distinction between RFR and ionizing radiation is often not made; consequently, the known hazards of ionizing radiation are linked--by implication--with exposure to RFR. In essence, ionizing radiation (which includes ultraviolet light, X-rays, and the emissions from radioactive materials) has sufficient quantum energy to expel an electron from a molecule, leaving the molecule positively charged and thereby strongly affecting its interactions with neighboring molecules. Ionization can alter the functions of biological molecules fundamentally and often irreversibly.

By contrast, the quantum energies of RFR are so much smaller that their primary effect is to agitate molecules rather than to ionize them. (The possibility of long-range quantum interactions is not excluded; however, evidence of their occurrence in live animals is sparse as yet, and there is no evidence that such effects would be harmful if they do occur.) Also, RFR-induced agitation ceases as soon as exposure to RFR is halted. At low RFR intensities, the heat that such agitation represents is well accommodated by the normal thermoregulatory capabilities of the biological organism exposed, and therefore such effects are generally reversible. At high RFR intensities, the thermoregulatory capabilities may be inadequate to compensate for such effects, and exposure at such intensities may lead to thermal distress or even irreversible thermal damage. In short, a single quantum of ionizing radiation that is absorbed by a molecule alters the properties of that molecule, and exposure to such radiation may thereby profoundly affect the function of the biological constituent involved, whereas the concurrent absorption of many quanta of RFR is necessary to cause biologically significant effects.

Even if an effect is produced by RFR, that effect may not necessarily be deleterious to the organism involved. As an example of a nonhazardous biological effect, the eyes must absorb light (a form of electromagnetic radiation having quantum energies above those of RFR but below those of the ionizing radiations mentioned previously) for vision. Light is also absorbed by the skin and at normal levels is converted into harmless heat. One of the reasons that the levels of allowable human exposure to RFR are generally lower in Eastern European countries than they are in the West is the philosophically

based assumption that even small RFR-induced effects are potentially harmful--
a view not generally shared in Western countries.

Concerned people often ask whether guarantees can be offered that
chronic exposure to low levels of an agent such as RFR will have dele-
terious effects many years in the future. It is scientifically impossible to
obtain data on which a guarantee of absolute safety can be based. However, the
large body of experimental data on the bioeffects of RFR indicates that,
unlike the ingestion of certain substances in small quantities that can
accumulate into a potentially harmful dose, RFR energy continually absorbed at
low incident power densities (dose rates) is readily dissipated and does not
accumulate in the body toward the equivalent of RFR energy absorbed at high
incident power densities. This is one of the basic reasons for the existence
of threshold power densities for the various RFR bioeffects.

## C.5 UNRESOLVED ISSUES

The potential biological effects of RFR have been assessed from existing
studies at frequencies up to 300 GHz. Based on the studies evaluated, with
recognition that the negative findings reported in some studies may have been
obtained because the experiments had been poorly conducted, there is no
reliable evidence to indicate that chronic exposure to RFR at incident average
power densities below 1 mW/cm$^2$ or at SARs below 0.4 W/kg is likely to be
hazardous to human health. However, certain gaps remain in our knowledge of
the biological effects of RFR. These gaps may be identified as follows:

(1)  Epidemiologic Studies. Epidemiologic studies of effects of human
     exposure to RFR in which the actual frequencies, levels, and durations
     of exposure are accurately known and quantified, are lacking. Existing
     epidemiologic studies, while extensive and reasonably well done, are
     subject to inherent defects, such as unavailability of complete sets of
     medical records, death certificates, or health questionnaires, or
     imprecise classification of the individuals with regard to RFR exposure.

(2)  Extrapolation of Findings on Animals to Humans. The most directly
     applicable experimental evidence relative to possible bioeffects of
     exposure to the RFR from any specific system such as the RS would be
     from studies in which humans were exposed to the frequencies and
     waveform characteristics of that kind of system for appropriate
     durations at the pulse and average power densities likely to be
     encountered. Further, quantitative evaluation of many biological
     end-points would be necessary. Such data, of course, do not exist.

Instead, data are obtained from laboratory animals (mostly small rodents) used as surrogates for humans, a standard practice for investigating the effects of other agents. Because of the biological differences among species, a basic uncertainty in this practice is its degree of validity, which depends in part on the species used, the nature of the agent and its quantitative aspects, and the biological endpoints studied. In investigations of RFR bioeffects, much progress has been achieved in quantifying exposures in terms of whole-body SARs and internal SAR distributions in animal carcasses and in physical and mathematical models of various species (including humans).

For example, such data can be used to determine what the whole-body SARs would be in humans at any frequency range, if, say, laboratory rats are exposed to 2.45 GHz RFR at prespecified power densities. Nevertheless, there are significant gaps in knowledge regarding internal SAR distributions in humans. Moreover, most such inter-species calculations do not endeavor to account for the roles of blood flow and other factors in determining heat flow patterns or of thermoregulatory mechanisms in mammals that maintain constant body temperatures.

(3) Thresholds and Long-Term, Low-Level Studies. Most experimental data indicating the existence of threshold power densities for various RFR bioeffects were obtained from exposures for relatively short durations. Although it is difficult to conceive of mechanisms whereby RFR exposures at well below threshold values over a long time could result in cumulative effects deleterious to health, there have been very few investigations involving exposure of animals to low-level RFR over a large fraction of their lifetime.

(4) Differential Bioeffects of Pulsed Versus CW RFR. Questions of quantitative and/or qualitative differences in bioeffects induced by pulsed versus CW RFR at equivalent average power densities cannot be resolved fully from current knowledge (i.e., some investigators have found no significant differences, whereas others have). Also, it should be noted that although the permissible average power densities in most current and proposed safety guidelines are applicable to both pulsed and CW RFR, these guidelines do not include maximum allowable pulse power densities per se. The draft 1991 ANSI/IEEE standard has begun to address peak value exposure conditions.

In the light of these gaps, the possibility that new information would reveal a significant hazard from chronic exposure to low levels of RFR cannot be dismissed, but is judged to be relatively low.

## C.6  CONCLUSIONS

Collectively, the results of the relatively few epidemiologic studies performed in the United States, the USSR, and other Eastern European countries are not regarded as evidence that environmental levels of RFR are likely to constitute a hazard to the general population.

Most U.S. experiments with animals that yielded recognizable and repeatable effects of exposure to RFR were performed at incident average power densities of more than about 2 mW/cm$^2$. Such effects are thermal in the sense that the RFR energy is absorbed by the organism as widely distributed heat that increases the whole-body temperature or as internally localized heat that is biologically significant even with natural heat-exchange and thermoregulatory mechanisms operating. The existence of threshold average power densities has been experimentally demonstrated for some effects and postulated for the others. Exposure to RFR at average power densities exceeding the threshold for a specific effect for a few minutes to a few hours (depending on the value) can cause irreversible tissue alterations. The heat produced by indefinitely long or chronic exposures at power densities well below the threshold is not accumulated because its rate of production is readily compensated for by heat-exchange processes or thermoregulation. Most investigations involving chronic exposures of mammals yielded either no effects or reversible, noncumulative behavioral or physiological effects for average power densities exceeding 2 mW/cm$^2$. In the few cases in which irreversible adverse effects of exposure were found, such effects were absent for average power densities below 2 mW/cm$^2$.

In a relatively small number of investigations, biological effects of RFR were reported at incident average power densities less than about 2 mW/cm$^2$. Such effects have been called "nonthermal," to distinguish them from those considered above. However, this usage of "nonthermal" is confusing and imprecise because the interaction mechanisms involved in each such effect differ considerably from those for the other effects, and clear distinctions between "thermal" and "nonthermal" based on precise scientific definitions of these terms are difficult to discern in the interactions.

Alterations of the blood-brain barrier that permit entry of normally blocked substances into brain tissue from its blood vessels have been reported for pulsed and CW RFR at average power densities as low as 0.03 mW/cm$^2$ but the effects at such low levels appear to be artifactual. Results of a subsequent study at 15 mW/cm$^2$ indicate that the technique used does not permit discrimination between changes in local cerebral blood flow and small alterations of the blood-brain barrier. Most experimental results indicate that significant localized heating of brain tissue is necessary to produce the effect.

The calcium-efflux phenomenon in brain-tissue preparations exposed to VHF or UHF RFR modulated at sub-ELF frequencies has been ascribed to complex, long-range quantum interactions, and such interactions are basically nonthermal. Most of the experiments to date were performed *in vitro*, with mixed results. Some of these results indicate that the phenomenon may occur in narrow amplitude "windows" for specific modulation frequencies, which may account in part for contradictory findings. However, very few experiments have been performed *in vivo* thus far.

One pulse power effect known to occur in humans is the detection of individual RFR pulses as apparent sound. This phenomenon has been characterized as nonthermal, primarily on the basis that the average power density would be minuscule if the time intervals between consecutive pulses were large. However, the average power density is not relevant, because the interactions that produce the effect are dependent primarily on the characteristics of individual pulses. For perception, a pulse power-density threshold of about 300 mW/cm$^2$ must be exceeded. No ill effects from this phenomenon have been reported, and human volunteers have been exposed to pulse power densities as high as 2,000 mW/cm$^2$ without apparent harm.

In summary, the review of the relevant literature indicates that there is no reliable scientific evidence to suggest that chronic exposure to the RFR from the RS outside the exclusion fence is likely to be deleterious to the health of even the most susceptible members of the population, such as the unborn, infirm, or aged.

## C.7 OTHER VIEWPOINTS

Some of the general concerns expressed following review of the Draft Environmental Impact Statements for other RFR installations were as follows: First, data on which to base an assessment of potential hazard to human health are insufficient; second, research on the effects of long-term, low-level exposures is only in its infancy; third, because little is currently known about the details of mechanisms of interaction of RFR with biological tissues, potentially hazardous effects that may occur have not been more precisely targeted for study; fourth, certain studies report effects at average power densities less than 0.1 mW/cm$^2$; fifth, even though some studies report negative findings (i.e., no effects as a result of RFR exposure), such negative findings can possibly be attributed to faulty experimental design or procedures; sixth, epidemiologic studies from the Soviet Union have reported various symptoms in persons exposed for many years to RFR at levels in the range from tenths to hundredths of a mW/cm$^2$--symptoms that when taken together are called the "microwave radiation syndrome"--but that such symptoms are not recognized in Western epidemiology studies; seventh, although we know much more today than we did 10 years ago, we will know even more 10 years from now and it is therefore likely that with this additional knowledge will come recognition of new, hazardous effects of long-term, low-level exposure to RFR; eighth, safe power thresholds for RFR exposure of the general population have not been established, and, further, safety standards vary from country to country; and ninth, research on possible alterations of genetic material and carcinogenic effects of long-term, low-level exposure to RFR has been insufficient.

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